

## 8. SITING CRITERIA

Several types of air quality and meteorological monitoring locations are needed to characterize community exposure, emissions sources, transport from one area to another, and background conditions. This section describes the different site characteristics and criteria for locating them.

### 8.1 Internal Siting Criteria

Internal criteria refer to the logistics of locating and servicing instruments for multi-year monitoring. These include:

- **Site commitment:** Several air quality and meteorological monitors will be located for more than a year, and a long-term commitment from the property owner for continued monitoring is required. Public buildings such as schools, fire stations, police stations, recreation halls, and hospitals often have more stability and a motive for public service than do private or commercial buildings. Meteorological sites, especially upper air, will require more remote locations away from obstacles and neighbors. Airports are often good candidates for remote sensing upper air sites.
- **Sufficient operating space:** A large, flat space, elevated at least 1 m but no more than 14 m above ground level, is needed to place monitors and monitoring probes. The space available for samplers should be at least 5 m distant and upwind (most common wind direction) from building exhausts and intakes and at least 2 m from walls, parapets, or penthouses that might influence air flow. Buildings housing large emitters, such as coal-, waste-, or oil-burning boilers, furnaces or incinerators, should be avoided.
- **Access and security:** Access to the sampling platform should be controlled by fencing or elevation above ground level. Sampler inlets should be sufficiently distant (>10 m) from public access to preclude purposeful contamination from reaching them in sufficient quantities to bias samples. Access should be controlled by a locked door, gate, or ladder with documentation of site visitations and the purposes of those visits. The site may need to be accessed at odd hours during intensive monitoring periods.
- **Safety:** Wiring, access steps, sampler spacing, and platform railings should comply with all relevant codes and workplace regulations, as well as common sense, to minimize potential for injury to personnel or equipment.
- **Power:** Power should be sufficient for the samplers to be operated on a long-term basis, as well as for special study and audit samplers to be located at a site. Where possible, a separate circuit breaker should be provided for each instrument to prevent an electrical malfunction in one monitor from shutting off power to the other monitors at the site.

- **Environmental control:** Environments surrounding monitoring instruments should be maintained within the manufacturers specifications for proper instrument function. Most FRM filter-based samplers are designed to operate under a wide range of environmental conditions and can be located outdoors in most types of weather. Several continuous monitoring methods may require environmental shelters with temperature and humidity controls to protect their electronic sensing and data acquisition mechanisms.

These internal criteria are costly and time consuming. For this reason, existing air quality or previously used upper air meteorology will be used to the greatest extent possible.

Larger spatial coverage will be obtained by the use of batter-powered filter and continuous monitors, especially at transport, source, and background sites. These can be located on power poles and rooftops without large logistical concerns. At most, a solar panel might be used to keep batteries charged between maintenance periods.

## 8.2 External Siting Criteria

External siting criteria refer to the environs surrounding a measurement location, and these differ depending on the zone of representation intended for a specific monitoring site.

- **Exposure:** Large nearby buildings and trees extending above the height of the monitor may present barriers or deposition surfaces. Certain trees may also be sources of PM in the form of detritus, pollen, or insect parts. These can be avoided by locating samplers by placing them >20 m from nearby trees, and twice the difference in elevation difference from nearby buildings or other obstacles.
- **Distance from nearby emitters:** The monitor should be outside the zone of influence of sources located within the designated zone of representation for the monitoring site. Neighborhood and urban zones of representation are needed for community-oriented compliance monitors. These should generally be at least 1 km from very large, visibly identifiable source areas occupied by major industries such as cement and steel production or ore processing. Regarding exhaust and road dust emissions from paved roads, Watson et. al., (1997) provide guidance on the recommended monitoring distances from paved roads with different levels of average daily traffic for neighborhood- and urban-scale sites. A minimum distance of ~50 m from busy paved highways is usually outside the road's immediate zone of influence for a rooftop monitor. These siting criteria were established for PM<sub>10</sub> monitoring siting (U.S. EPA, 1987), and they have proven their validity in PM<sub>10</sub> network design. For larger than middle-scale monitoring, no unpaved roads with significant traffic or residential wood-burning appliances should be located within 100 m of the monitoring location. Background monitoring sites should be located >100 km from large population centers, and >100 m from roads and wood burning (burning is common, though often intermittent, in camping, forested, and agricultural areas).

- **Proximity to other measurements:** Other air quality and meteorological measurements can aid in the interpretation of high PM levels, and with all other considerations being equal, PM<sub>2.5</sub> sites should give preference to existing sites that make other measurements. For example, high local wind gusts may explain high PM readings as caused by wind blown dust. These gusts are often localized, and would not be detected on a more distant monitor. Similarly, a strong correspondence between hourly CO and PM readings would indicate that locally emitted vehicle exhaust is a large contributor at that site. This conclusion would be more tenuous if the CO measurements were not collocated. In particular, collocating PM<sub>10</sub> and PM<sub>2.5</sub> monitors will provide information on the size distribution of suspended particles.

### **8.3 Site Classifications**

Several types of sites will be selected for specific purposes that are described in Section 4. These site types are intended to represent the following.

#### **8.3.1 Community-Representative Sites**

Community-representative (CORE) monitoring sites are beyond the zone of influence of a single source, and should have neighborhood- to urban- scale zones of representation. The principal purpose of community-oriented monitoring sites is to approximate the short-term and long-term exposures of large numbers of people where they live, work, and play.

#### **8.3.2 Transport Sites**

Regional transport (or boundary) monitors are located between the populated areas to determine how much of the PM at community-oriented sites derives from external sources. Background sites are intended to quantify regionally representative PM<sub>2.5</sub> for sites located away from populated areas and other significant emission sources. Transport sites are intended to measure fine particle contributions from upwind source areas, or mixtures of source areas, that move into a community exposure area.

Transport sites should be located upwind of planning area boundaries, outside of the urban-scale zone of influence. For the most part, transport sites are between planning areas, or between districts containing large emitters (e.g., industrial complexes, isolated point sources) and a planning area. Measurements from transport sites represent transport into the planning area only during periods when the wind is from the direction of the external source area toward the planning area. During other periods, the transport site may also serve the purposes of a background site, or as a transport site for another planning area. For this reason, transport site locations are selected to achieve multiple purposes. Meteorological data needed to evaluate which purposes are being served should be available along with the PM<sub>2.5</sub> measurements.

### **8.3.3 Background Sites**

Background monitors are intended to measure  $PM_{2.5}$  concentrations that are not dependent on upwind sources, although the particles they quantify will be a mixture of natural and manmade source material. These stations should be distant from identified emitters, and may be at higher elevations than the urban-scale community exposure monitors. Current IMPROVE monitoring sites in Central California (Eldred et. al., 1990) are good examples of background monitoring sites.

Properly sited background stations should measure  $PM_{2.5}$  typical of the lowest ambient concentrations in a state or region. These sites should not be along transport pathways, though in densely populated or industrialized regions a given sample may or may not be along such a pathway depending on which way the wind is blowing.

### **8.3.4 Source Zone of Influence Sites**

Source zone of influence sites are placed right next to and downwind (of prevailing wind) a suspected emissions source, such as a major roadway, construction site, or industry. These are intended to determine the distance within which the source dominates PM concentrations at a receptor, in conjunction with other sites located outside of the zone of influence of a specific source.

### **8.3.5 Receptor Zone of Representation Sites**

Receptor zone of representation sites are intended to quantify the variability in PM concentrations around a fixed monitoring location or within a modeling grid square. These determine the extent to which the fixed monitoring site represents exposures in its vicinity. Distances from the base site range from 100 m to half the size of a typical modeling grid cell (~2.5 km).

### **8.3.6 Gradient Sites**

Gradient sites are located between base sites and are used to quantify changes in concentration between the sites; these sites are located away from visible emitters. Boundary sites are located outside of the urban area, near the edges of the modeling domain, to determine background concentrations that come from outside the planning area.

## **8.4 Surface Meteorological Sites**

Surface meteorological monitors are to be located away from obstructions with good exposure.

## **8.5 Meteorological and Experimental Tower**

A 100 m agl scaffold type tower will facilitate meteorological, air quality, and fog measurements in the vertical. This tower will be located in an agricultural field with ~ 1 km of fetch without obstructions such as buildings. Alfalfa or grazing pasture is appropriate for this. The field should be in the midst of cotton fields, probably east of Corcoran. Much of the land east of Corcoran within a 10 km radius is pasture, native vegetation and cotton fields. It should be upwind by 1 km of a large dairy or feedlot for the fall nitrate study. A careful site inspection should be taken since there are numerous dairies and feedlots surrounding the Corcoran area. The tower should be installed at least 200 m from any power lines. The tower site should have available at least a 110 meter circular area to allow for the guy wires.

Air traffic control permission and requirements must first be determined for this tower. It cannot be near airline flight paths and should not interfere with crop dusters. Installing meteorological sensors on existing towers such as radio, cellular or television is an option although permission would likely be denied since the sensors may interfere electrically with the broadcasting signal.

## **8.6 Profiler and Sodar Sites**

These must have 100 m of fetch on all sides and no tall buildings, trees or other obstructions within 500 m.

## **8.7 Radiosonde Launch Sites**

These must be located at least 1 km away from high power lines in an area with low buildings that do not block radio transmissions. Release of these balloons may require FAA approval if they are near an airport.

## 9. PARTICLE MEASUREMENT METHODS

This section examines alternatives for continuous, filter-based, and fog measurements of particle and precursor gas chemistry. It evaluates and justifies the selection of practical alternatives for application during CRPAQS field studies. These descriptions will be enhanced with results from the measurement evaluation study and after measurement investigators have been selected.

### 9.1 Continuous Particle and Precursor Gas Measurement Methods

Previous sections have emphasized the need for high time resolution (one-hour or less) PM measurements of particle mass and chemical components. Watson et al. (1998) surveyed the available instruments in this category and examined the extent to which they are equivalent to, or can be used to predict, PM<sub>2.5</sub> mass concentrations. Watson et al. (1997; 1998) concluded that commonly available TEOM and beta attenuation monitors can yield equivalent particle mass concentrations when the aerosol is non-volatile, as is largely the case in central California during spring, summer, and part of the fall. Richards et al. (1998) showed that nephelometer measurements of light scattering, both those with heated inlets to evaporate aerosol liquid water, and those with unheated inlets, were highly correlated with, and could be used to predict, collocated PM<sub>2.5</sub> filter measurements when relative humidity adjustments were applied. The limitation to the application of continuous mass monitors in CRPAQS field studies occurs when ammonium nitrate is a large PM<sub>2.5</sub> component. As discussed earlier, this occurs sometimes during the fall and nearly always during winter.

IMS-95 revealed the logistical and technical difficulties in acquiring wintertime measurements with sequential 3-hour resolution by filter sampling. Even with this frequent sampling, information was lost during the crucial 1000 to 1900 PST period when there appears to be rapid coupling between the surface layer and the valleywide layer. These details cannot be practically and economically captured with sequential filter measurements. However, several technologies are now available, or are expected to be available by 1999, to continuously quantify some of the relevant PM<sub>2.5</sub> chemical components and precursor gases.

Table 9.1-1 summarizes available continuous monitoring technologies. Continuous monitors are classified by the properties that they measure with respect to mass (i.e., inertial mass, beta-ray attenuation, pressure drop), interactions with light (i.e., scattering and absorption), condensation, mobility (i.e., electrical mobility, differential mobility), chemical components (i.e., single particle characteristics, carbon, sulfur, nitrate, and elements), and precursor gases (i.e., ammonia, nitric acid, sulfur dioxide). Table 9.1-1 shows that there are several approaches to measuring the same property as well as multiple providers for these instruments. More detail is given by Baron et al. (1993), Gebhart (1993), Rader and O'Hern (1993), Williams et al. (1993), Pui and Swift (1995), and Watson et al. (1998), as well as in the cited references. The technologies selected for CRPAQS field studies, and the rationales for their selections, are:

- **PM<sub>2.5</sub> and PM<sub>10</sub> TEOM:** TEOMs will be configured with both PM<sub>2.5</sub> and PM<sub>10</sub> inlets. TEOMS have previous operated with 50°C inlet temperature to prevent water vapor condensation and provide a standard sample condition, even though

this high temperature dissociates ammonium nitrate into nitric acid and ammonia (Allen et al., 1997). New TEOM models are intended to operate at the constant temperature (20 °C) and relative humidity (30%) conditions that apply to Federal Reference Method filter equilibration. . The practicality and utility of these modified TEOMs will be evaluated in the January 1999 methods evaluation study. Meyer et al. (1992) showed ~30% more PM<sub>10</sub> mass was obtained with a 30°C TEOM sampling beside a 50°C TEOM in the woodburning-dominated environment at Mammoth Lakes, CA. TEOMs will be operated with their nominal flow rates of 3 L/min (16.7 L/min through the inlets)

- **PM<sub>2.5</sub> nephelometer:** Table 9.1-2 identifies available nephelometers that measure a fraction of the light scattered by particles of different size. Integrating nephelometers are a widely-used subset that quantify particle light scattering in nearly all directions, while the remainder sense the scattered light in a particular direction. Although light scattering is often highly correlated with mass concentrations, the relationship depends on several variables and may be different from location to location and for different seasons of the year. The particle scattering efficiency depends on particle size, real and imaginary parts of the refractive index, and particle shape. In practice, particle scattering efficiencies are empirically determined by collocating nephelometers with filter-based samplers and comparing their measurements. This is facilitated in the Grimm and MIE units by allowing a 47 mm filter to be placed in the exhaust stream for subsequent weighing and chemical analysis. The Grimm measures forward scattering intensities for individual particles, thereby providing estimates of the particle size distribution as well as total mass. The Grimm, MIE, Met-1, and TSI DUSTRAK are small, possess internal data acquisition systems that can download to a laptop computer, and are battery powered. They range in cost from ~\$2K (DUSTRAK) to \$12K (Grimm) and are well-suited for location at satellite sites in conjunction with Minivol samplers to better understand the arrival of particulate concentration pulses and the zone of representation of these monitoring sites. For the annual average campaign, these continuous measurement devices will be operated on as many days as feasible between the sixth-day filter sampling to identify events that might not be captured by the staggered sampling frequency. Portable nephelometers will be operated at 5 minute averaging intervals at core and selected satellite sites during the annual, winter, and fall studies. Figure 9.1-1 shows an example of hourly average light scattering expressed as approximate mass concentration measured with a DUSTRAK nephelometer.
- **PM<sub>2.5</sub> elemental carbon aethalometer:** The aethalometer quantifies elemental or black (BC) carbon by light transmission. This is a major indicator of urban emissions. It will be the main instrument that tracks the surface concentrations of primary urban emissions on middle-, neighborhood, urban, and regional scales. Figure 9.1-2 shows what is expected from urban and non-urban sites. The spikes at both sites represent local sources that can be subtracted from the total. The increments at the urban site represent the urban-scale increment. The afternoon similarities (minus the spikes) show the effects of vertical and horizontal mixing.

The aethalometer converts the result of its filter attenuation measurement into BC mass concentration by a conversion factor of  $19 \text{ m}^2/\text{g}$ . Aethalometer BC agrees with collocated filter samples analyzed for elemental carbon (Hansen and McMurry, 1990), and this is not site independent. Similar to the situation with the nephelometer, the relationship between aethalometer output and elemental carbon must be established empirically by comparison with collocated filter measurements.

- Thermal combustion carbon analyzer:** The Ambient Carbon Particulate Monitor (ACPM, R&P Series 5400) (Rupprecht et al., 1995) defines organic carbon as that which volatilizes at  $250^\circ\text{C}$  (a value that can be changed) and elemental carbon as the remaining amount that volatilizes at  $750^\circ\text{C}$  (a value that can also be changed). This is another operational definition that corresponds to organic carbon fractions reported by the commonly applied Thermal Optical Reflectance (Chow et al., 1993) method, but it is necessarily equivalent to the organic and elemental carbon fractions that are commonly reported.
- Flash volatilization nitrate analyzer:** This method uses an integrated collection and vaporization cell whereby particles are collected by a humidified impaction process, and analyzed in place by flash vaporization. The approach is similar to the manual method used for over twenty years for measuring the size distribution of sulfate aerosols (Roberts and Friedlander., 1976; Hering and Friedlander, 1982). The difference is that the particle collection and analysis has been combined into a single cell, allowing the system to be automated. Although the automated method that has been recently tested is specific to nitrate, the same technology could be applied for continuous sulfate measurements by using a sulfur detector instead of a nitric oxide detector. Figure 9.1-3 shows an example of how these data can be used determine particle nitrate incursions. This will be needed to test the hypotheses of down mixing from aloft during the afternoon. During the Northern Front Range Air Quality Study in Colorado, the first prototype monitor captured the 12-minute time variability in fine particle nitrate concentrations with a precision of approximately  $\pm 0.5 \text{ } \mu\text{g}/\text{m}^3$  (Chow et al., 1998b). A comparison with denuded filter measurements followed by ion chromatographic analysis (Chow and Watson, 1998b) showed agreement within  $\pm 0.6 \text{ } \mu\text{g}/\text{m}^3$  for most of the measurements, but exhibited a discrepancies the elevated nitrate periods. Additional data is needed to qualify the accuracy and comparability of the method. The method has been applied in SCOS-97 and the data are being evaluated.
- Flash volatilization sulfur analyzer:** This instrument is similar to the flash volatilization nitrate analyzer, but it uses a sulfur detector in place of a nitric oxide detector. An instrument has recently been developed that will be deployed in the methods evaluation study.
- Chemiluminescent ammonia analyzer:** Chemiluminescent ammonia analyzers convert ammonia to  $\text{NO}_x$  by thermal oxidation using a catalytic technique at high temperature. This type of continuous ammonia monitor has been used mostly in



source emission testing rather than ambient monitoring in the past. Laboratory tests of TEI Model 42 (Thermo Environmental Instruments, Franklin, MA) during the Northern Front Range Air Quality Study (Chow et al., 1998) show that: 1) typical response time is on the order of two or more hours for concentrations of 40 ppb to 400 ppb; 2) the instrument's detection limit is approximately 10 ppb (ambient concentration); 3) oxidizer efficiency is in the range of 50% to 75% and lower for  $\text{NH}_3$  concentrations less than 40 ppb; and 4) no effects upon ammonia concentrations could be identified by the changes in ambient relative humidity. This was a prototype instrument, however, and TEI has made improvements in the technology that may make the instrument more accurate and precise.

- Nitric acid analyzer:** Atmospheric nitric acid ( $\text{HNO}_3$ ) concentrations can be monitored by conversion of nitric acid to nitrogen dioxide ( $\text{NO}_2$ ), followed by detection with a chemiluminescent analyzer (Kelly et al., 1979; Burkhardt et al., 1988; Harrison and Msibi, 1994). While conversion methods from nitric acid to nitrogen dioxide are not very selective, nylon filters have been used to remove nitric acid from a gas stream. The nitric acid concentration is therefore determined by the difference in  $\text{NO}_2$  measurements with and without a nylon filter in the gas stream. The sampled gas is initially passed through a Teflon filter to remove particles. This is followed by the nylon filter that removes more than 99% of the nitric acid and can be bypassed for using the difference method. Conversion from nitric acid to  $\text{NO}$  and  $\text{NO}_2$  is achieved with a glass bead converter operating at high temperature (i.e., 350 to 400 °C). This is followed by a  $\text{CrO}_3$  impregnated filter used to convert  $\text{NO}$  to  $\text{NO}_2$  (Ripley et al., 1964). A chemiluminescence instrument (Fehsenfeld et al., 1990; Gregory et al., 1990) is used to measure the resulting  $\text{NO}_2$  concentration, with luminol based instruments being particularly sensitive (Kelly et al., 1990). These instruments have a sensitivity around 100 ppt with a time response of about 5 minutes (Harrison, 1994). Limitations of the technique are due to the sticking of nitric acid to walls and to the possible interference of high humidity with conversion processes (e.g., Burkhardt et al., 1988). These instruments have been tested in intercomparison studies (Hering et al., 1988; Fehsenfeld, 1998).
- TECO 43a Sulfur Dioxide Analyzer:** This pulsed fluorescence monitor can detect sulfur dioxide to 0.1 ppb levels and is appropriate for detecting the arrival of nearby sulfur emitters.
- Single Particle Mass Spectrometer:** These devices measure the size and chemical composition of individual particles. Portable instruments for ground based monitoring are becoming available (e.g., Gard et al., 1997), and an airborne instrument for measurements in the troposphere and lower stratosphere is being developed (Murphy and Schein, 1998). These instruments have been recently developed and are incompletely characterized with respect to ionization thresholds of aerosol particles (Thomson and Murphy, 1993; Thomson et al., 1997), trade-offs between aerodynamic particle sizing and OPC sizing coupled with mass spectroscopy (Salt et al., 1996), and the ability to determine surface and total composition of the aerosol particles (Carson et al., 1997). Applications of

this technique have included characterizing aerosol composition in support of the 1993 OH experiment at Idaho Hill, CO (Murphy and Thomson, 1997a, 1997b), examining the purity of laboratory-generated sulfuric acid droplets (Middlebrook et al., 1997), determining halogen, (Murphy et al., 1997), speciating sulfur (Neubauer et al., 1996), studying matrix-assisted laser desorption/ionization (Mansoori et al., 1996), monitoring pyrotechnically derived aerosol in the troposphere (Liu et al., 1997), characterizing automotive emissions (Silva and Prather, 1997), and measuring marine aerosols (Noble and Prather, 1997). Nevertheless, this is a rapidly advancing technology that is certain to provide useful CRPAQS information.

## **9.2 Particle Filter Measurements**

Particle filtration samplers consist of combinations of size-selective inlets, filter media, filter holders, and flow movers/controllers. Denuder systems and absorbing materials that capture gases associated with volatile species such as ammonium nitrate and some organic compounds can be installed behind the size-selective inlet and behind the particle collection filter. The dimensions, materials, and construction of these components affect the particles that are measured. Chow and Watson (1998) summarize and provide references for particle sampling methods and their components.

Andersen single channel FRM and sequential filter samplers will be used to acquire filter samplers at core sites at the backbone sites. Several speciation samplers are being tested as part of an EPA program during January 1999, and these are also to be deployed at the backbone network. EPA speciation samplers typically use flow rates of ~7 L/min, and these are too low for samples less than 24-hour duration and for background site monitoring. Sequential FRMs draw air through a PM<sub>10</sub> inlet that is a modification to the SA-246 inlet used on the dichotomous sampler. Current designs might be modified so that two samplers can be operated in parallel with appropriate denuders and backup filters to acquire concentrations on a Teflon filter, for gravimetric and elemental analysis, and on a quartz filter backed by a sodium chloride impregnated filter for ion and carbon analysis. Although the inlet and transfer pipes probably remove most nitric acid, an anodized aluminum denuder (John et al., 1985) will probably be needed located after the PM<sub>10</sub> inlet to assure that nitric acid is removed and that only volatilized nitrate is collected on the backup filter.

Airmetrics Minivol samplers will be used at satellite sites with the same filter configuration. These battery-powered portable units operate at 5 L/min and can be located nearly anywhere without need for logistical support.

Table 9.2-2 evaluates lower quantifiable limits for elements, ions, and carbon for different flow rates. While the 5 L/min and 16.7 L/min are adequate for 24-hour sampling, they are not sufficient for 3-hour sampling, especially for carbon and mass concentrations. The 110 L/min flow rate proved to be more than enough flow during IMS-95 for three-hour samples, and this could be halved while still acquiring enough sample for laboratory analysis. If the continuous carbon mass, and nitrate measurement devices prove themselves during the measurement evaluation study, then it could be feasible to use only the Teflon channel over three-hour intervals for elemental analysis. By applying high sensitivity XRF or PIXE to

these samples, adequate data could be achieved with the sequential FRM over periods as short as 3-hours duration.

**Table 9.1-1**  
**Summary of Continuous Monitoring Technology**

<u>Instrument</u>	<u>Quantity Measured</u>	<u>Methodology</u>
<b><i>I. Mass and Mass Equivalent</i></b>		
<b>Tapered Element Oscillating Microbalance (TEOM)<sup>y</sup></b> (Patashnick and Hemenway, 1969; Patashnick, 1987; Patashnick and Rupprecht, 1991; Meyer et al., 1992; Rupprecht et al., 1992; Allen et al., 1997)	Particle mass. Detection limit ~ 5 µg/m <sup>3</sup> for a five minute average.	Particles are continuously collected on a filter mounted on the tip of a glass element which oscillates in an applied electric field. The glass element is hollow, with the wider end fixed; air is drawn through the filter and through the element. The oscillation of the glass element is maintained based on the feedback signal from an optical sensor. The resonant frequency of the element decreases as mass accumulates on the filter, directly measuring inertial mass. The typical signal averaging period is 10 minutes. Temperatures are maintained at a constant value, typically 30°C or 50°C, to minimize thermal expansion of the tapered element.
<b>Piezoelectric Microbalance<sup>d</sup></b> (Olin and Sem, 1971); Sem et al., 1977; Fairchild and Wheat, 1984; Bowers and Chuan, 1989; Ward and Buttry, 1990; Noel and Topart, 1994)	Particle mass. Detection limit ~ 10 µg/m <sup>3</sup> for a one minute average.	Particles are deposited by inertial impaction or electrostatic precipitation onto the surface of a piezoelectric quartz crystal disk. The natural resonant frequency of the crystal decreases as particle mass accumulates. The changing frequency of the sampling crystal is electronically compared to a clean reference crystal, generating a signal that is proportional to the collected mass. The reference crystal also allows for temperature compensation.
<b>Beta Attenuation Monitor (BAM)<sup>i,af</sup></b> (Nader and Allen, 1960; Spurny and Kubie, 1961; Lilienfeld and Dulchinos, 1972; Husar, 1974; Cooper, 1975; Lilienfeld, 1975; Sem and Borgos, 1975; Cooper, 1976; Macias, 1976; Jaklevic et al., 1981; Courtney et al., 1982; Klein et al., 1984; Wedding and Weigand, 1993; Speer et al., 1997)	Particle mass. Detection limit ~ 5 µg/m <sup>3</sup> for a one hour average	Beta rays (electrons with energies in the 0.01 to 0.1 MeV range) are attenuated according to an approximate exponential (Beer's Law) function of particulate mass, when they pass through deposits on a filter tape. Automated samplers utilize a continuous filter tape, first measuring the attenuation through the unexposed segment of tape to correct for blank attenuation. The tape is then exposed to ambient sample flow, accumulating a deposit. The beta attenuation measurement is repeated. The blank-corrected attenuation readings are converted to mass concentrations, with averaging times as short as 30 minutes.
<b>Pressure Drop Tape Sampler (CAMMS)<sup>k,ag</sup></b> (Babich et al., 1997)	Particle mass. Detection limit ~ 2 µg/m <sup>3</sup> for a one hour average	CAMMS (continuous ambient mass monitor system) measures the pressure drop across a porous membrane filter (Fluoropore). For properly chosen conditions, the pressure drop is linearly correlated to the particle mass deposited on the filter.

**Table 9.1-1 (continued)**  
**Summary of Continuous Monitoring Technology**

<u>Instrument</u>	<u>Quantity Measured</u>	<u>Methodology</u>
<b>II. Visible Light Scattering</b>		
<b>Nephelometer</b> <sup>c,n,p,r,x,y,aa</sup> (Mie, 1908; Koschmieder, 1924; Beuttell and Brewer, 1949; Ahlquist and Charlson, 1967, 1969; Charlson et al., 1967, 1968, 1969; Quenzel, 1969a, 1969b; Horvath and Noll, 1969; Borho, 1970; Ensor and Waggoner, 1970; Garland and Rae, 1970; Heintzenberg and Hänel, 1970; Rae and Garland, 1970; Rae, 1970a; Rae, 1970b; Ruppertsberg, 1970; Covert et al., 1972; Ensor et al., 1972; Thielke et al., 1972; Bhardwaja et al., 1973; Heintzenberg and Quenzel, 1973a; Heintzenberg and Quenzel, 1973b; Rabinoff and Herman, 1973; Bhardwaja et al., 1974; Charlson et al., 1974a, 1974b; Quenzel et al., 1975; Heintzenberg, 1975, 1978; Heintzenberg and Bhardwaja, 1976; Harrison, 1977a, 1977b, 1979; Sverdrup and Whitby, 1977; Bodhaine, 1979; Heintzenberg and Witt, 1979; Heintzenberg, 1980; Mathai and Harrison, 1980; Waggoner and Weiss, 1980; Wiscombe, 1980; Harrison and Mathai, 1981; Johnson, 1981; Malm et al., 1981; Ruby and Waggoner, 1981; Waggoner et al., 1981; Winkler et al., 1981; Larson et al., 1982; Hasan and Lewis, 1983; Heintzenberg and Bäcklin, 1983; Waggoner et al., 1983; Hitzengerger et al., 1984; Gordon and Johnson, 1985; Rood et al., 1985, 1987; Ruby, 1985; Wilson et al., 1988; Barber and Hill, 1990; Trijonis et al., 1990; Bodhaine et al., 1991; Sloane et al., 1991; Nyeki et al., 1992; Optec Inc., 1993; Eldering et al., 1994; Horvath and Kaller, 1994; White et al., 1994; Mulholland and Bryner, 1994; Lowenthal et al., 1995; Anderson et al., 1996; Heintzenberg and Charlson, 1996; Watson et al., 1996; Rosen et al., 1997; Anderson and Ogren, 1998; Moosmüller et al., 1998)	<i>In-situ</i> , integrated light scattering from particles and gases; a direct estimate of the aerosol light-scattering coefficient, $b_{\text{scat}}$ ; lower detection limit $\sim 1 \text{ Mm}^{-1}$ for a ten minute average.	Ambient gases and particles are continuously passed through an optical chamber; the chamber is generally in the form of a long cylinder illuminated from one side, perpendicular to the long axis of the chamber. The light source is located behind a lambertian diffuser and illuminates the aerosol at visible wavelengths. Light is scattered by particles in the chamber over angles ranging from $0^\circ$ to $180^\circ$ ; mounted behind a series of baffles, a photomultiplier tube located at one end of the chamber detects and integrates the light scattered over about $9^\circ$ to $171^\circ$ . The light detected by the photomultiplier is usually limited by filters to wavelengths in the 500 to 600 nm range, corresponding to the response of the human eye. The instrument is calibrated by introducing gases of known index of refraction, which produce a known scattered energy flux. (For this purpose, halocarbon gases must now be replaced by non-ozone-reactive alternatives.) A typical signal averaging period is about 2 minutes.

**Table 9.1-1 (continued)**  
**Summary of Continuous Monitoring Technology**

<u>Instrument</u>	<u>Quantity Measured</u>	<u>Methodology</u>
<b>Optical Particle Counter/Size Spectrometer</b> <sup>j,u,v,aa</sup> (Gucker et al., 1947a, 1947b; Gucker and Rose, 1954; Whitby and Vomela, 1967; Whitby and Liu, 1968; Liu et al., 1974c; Heintzenberg, 1975, 1980; Hindman et al., 1978; Mäkynen et al., 1982; Chen et al., 1984; Robinson and Lamb, 1986; van der Meulen and van Elzakker, 1986; Wen and Kasper, 1986; Buettner, 1990; Gebhart, 1991; Hering and McMurry, 1991; Kaye et al., 1991; Sloane et al., 1991; Eldering et al., 1994; Kerker, 1997; Fabiny, 1998)	Number of particles in the 0.1 to 50 µm size range.	Light scattered by individual particles traversing a light beam is detected at various angles; these signals are interpreted in terms of particle size via calibrations.
<b>Condensation Nuclei (CN) Counter</b> <sup>aa</sup> (Liu and Pui, 1974; Sinclair and Hoopes, 1975; Bricard et al., 1976; Agarwal and Sem, 1980; Liu et al., 1982; Miller and Bodhaine, 1982; Bartz et al., 1985; Ahn and Liu, 1990; Noone and Hansson, 1990; Su et al., 1990; Zhang and Liu, 1990; Keston et al., 1991; McDermott et al., 1991; Stolzenburg and McMurry, 1991; Zhang and Liu, 1991; Saros et al., 1996)	Number of nucleating particles (particles in the ~0.003 to 1 µm size range).	Particles are exposed to high supersaturations (150% or greater) of a working fluid such as alcohol; droplets are subsequently nucleated, allowing detection of the particles by light scattering.
<b>Aerodynamic Particle Sizer</b> <sup>aa</sup> (Wilson and Liu, 1980; Kasper, 1982; Chen et al., 1985; Baron, 1986; Chen and Crow, 1986; Griffiths et al., 1986; Wang and John, 1987; Ananth and Wilson, 1988; Brockmann et al., 1988; Wang and John, 1989; Brockmann and Rader, 1990; Chen et al., 1990; Cheng et al., 1990, 1993; Lee et al., 1990; Rader et al., 1990; Heitbrink et al., 1991; Marshall et al., 1991; Heitbrink and Baron, 1992; Peters et al., 1993)	Number of particles in different size ranges.	Parallel laser beams measure the velocity lag of particles suspended in accelerating air flows.

**Table 9.1-1 (continued)**  
**Summary of Continuous Monitoring Technology**

<u>Instrument</u>	<u>Quantity Measured</u>	<u>Methodology</u>
<b>LIDAR</b> <sup>e,f,h,i,s,t</sup> (Hitschfeld and Bordan, 1954; Fiocco et al., 1971; Fernald, 1972; Melfi, 1972; Rothe et al., 1974; Cooney, 1975; Woods and Jolliffe, 1978; Klett, 1981; Aldén et al., 1982; Browell, 1982; Browell et al., 1983; Measures, 1984; Force et al., 1985; McElroy and Smith, 1986; Ancellet et al., 1987, 1989; Edner et al., 1988; Galle et al., 1988; Alvarez II et al., 1990; Beniston et al., 1990; de Jonge et al., 1991; Grund and Eloranta, 1991; Ansmann et al., 1992; Kölsch et al., 1992; McElroy and McGown, 1992; Milton et al., 1992; She et al., 1992; Whiteman et al., 1992; Kovalev, 1993, 1995; Moosmüller et al., 1993; Gibson, 1994; Kempfer et al., 1994; Kovalev and Moosmüller, 1994; Piironen and Eloranta, 1994; Zhao et al., 1994; Grant, 1995; Toriumi et al., 1996; Evans et al., 1997; Hoff et al., 1997; Moosmüller and Wilkerson, 1997)	Range resolved atmospheric backscatter coefficient ( $\text{cm}^2/\text{steradian}$ ) and gas concentrations.	A short laser pulse is sent into the atmosphere, backscattered light from gas and aerosols is detected as a function of time of flight for the light pulse. This results in a range resolved measurement of the atmospheric backscatter coefficient if extinction is properly accounted for. Special systems which separate molecular and aerosol scattering have an absolute calibration and extinction and backscatter ratio can be retrieved. Differential absorption lidars use multiple wavelengths and utilize the wavelength dependent absorption of atmospheric gases to retrieve their range resolved concentrations.
<b>III. Visible Light Absorption</b>		
<b>Aethalometer</b> <sup>m,z</sup> (Hansen et al., 1984, 1988, 1989; Rosen et al., 1984; Hansen and Novakov, 1989, 1990; Hansen and McMurry, 1990; Hansen and Rosen, 1990; Parungo et al., 1994; Pirogov et al., 1994)	Light absorption, reported as concentration of elemental carbon. Detection limit ~ $0.1 \mu\text{g}/\text{m}^3$ black carbon for a one minute average.	Ambient air is continuously passed through a quartz-fiber filter tape. Light-absorbing particles such as black carbon cause attenuation of a light beam. By assuming that all light-absorbing material is black carbon, and that the absorption coefficient of the black carbon is known and constant, the net attenuation signals can be converted into black carbon mass concentrations. The time resolution of the aethalometer is on the order of a fraction of a minute depending on ambient black carbon concentration.
<b>Particle Soot/Absorption Photometer (PSAP)</b> <sup>x</sup> (Bond et al., 1998; Quinn et al., 1998)	Light absorption detection limit $\sim 0.2 \text{ Mm}^{-1}$ for a five-minute average. For an absorption efficiency of $10 \text{ m}^2/\text{g}$ , this would correspond to $20 \text{ ng}/\text{m}^3$ of black carbon.	The PSAP produces a continuous measurement of absorption by monitoring the change in transmittance across a filter (Pallflex E70-2075W) for two areas on the filter, a particle deposition area and a reference area. A light emitting diode (LED) operating at 550 nm, followed by an Opal glass serves as light source. The absorption reported by the PSAP is calculated with a nonlinear equation correcting for the magnification of absorption by the filter medium and for response nonlinearities as the filter is loaded.

**Table 9.1-1 (continued)**  
**Summary of Continuous Monitoring Technology**

<u>Instrument</u>	<u>Quantity Measured</u>	<u>Methodology</u>
<b>Photoacoustic Spectroscopy</b> <sup>g,ag</sup> (Bruce and Pinnick, 1977; Pao, 1977; Terhune and Anderson, 1977; Lin and Campillo, 1985; Adams, 1988; Adams et al., 1989, Arnott et al., 1995; Petzold and Niessner, 1995, 1996; Bijnen et al., 1996; Moosmüller and Arnott, 1996; Moosmüller et al., 1997; Arnott et al., 1998; Moosmüller et al., 1998)	Light absorption, reported as black carbon. Detection limit ~ 50 ng/m <sup>3</sup> for a ten-minute average.	Ambient air is aspirated through a resonant chamber, where it is illuminated by modulated (chopped) laser light at a visible wavelength (e.g., 514.5 nm). Light-absorbing particles, principally elemental carbon, absorb energy from the laser beam and transfer it as heating of the surrounding air. The expansion of the heated gas produces a sound wave at the same frequency as the laser modulation. This acoustic signal is detected by a microphone; its signal is proportional to the amount of absorbed energy. The illumination must be carefully chosen to avoid atmospheric gaseous absorption bands.
<b>IV. Electrical Mobility</b>		
<b>Electrical Aerosol Analyzer (EAA)</b> <sup>aa</sup> (Whitby and Clark, 1966; Liu et al., 1974a, 1974b; Liu and Pui, 1975; Helsper et al., 1982)	Number of particles in the sub-micrometer size range (~ 0.01 to 1.0 µm).	Particles are collected according to their size-dependent mobilities in an electric field. The collected particles are detected by their deposition of charge in an electrometer.
<b>Differential Mobility Particle Sizer (DMPS)</b> <sup>aa</sup> (Knutson and Whitby, 1975a, 1975b; Hoppel, 1978; Alofs and Balakumar, 1982; Hagen and Alofs, 1983; Fissan et al., 1983; ten Brink et al., 1983; Kousaka et al., 1985; Reineking and Porstendörfer, 1986; Wang and Flagan, 1990; Reischl, 1991; Winklmayr et al., 1991; Zhang et al., 1995; Birmili et al., 1997; Endo et al., 1997)	Number of nucleating particles in different size ranges (~ 0.01 to 1.0 µm size range).	Particles are classified according to their mobility in an electric field, which is a function of their size; a condensation nuclei counter then counts the population in a size "bin".



**Table 9.1-1 (continued)**  
**Summary of Continuous Monitoring Technology**

<u>Instrument</u>	<u>Quantity Measured</u>	<u>Methodology</u>
<b><i>V. Chemical-Specific Particle Monitors</i></b>		
<b>Single Particle Mass Spectrometer (RSMS, PALMS, ATOFMS)</b> <sup>ad,ae,af,ag</sup> (Thomson and Murphy, 1993; Mansoori et al., 1994; Murphy and Thomson, 1994, 1995; Noble et al., 1994; Nordmeyer and Prather, 1994; Prather et al., 1994; Carson et al., 1995; Johnston and Drexler, 1995; Mansoori et al., 1996; Neubauer et al., 1996; Noble and Prather, 1996, 1997, 1998; Salt et al., 1996; Carson et al., 1997; Gard et al., 1997, 1998; Liu et al., 1997; Middlebrook, 1997; Murphy and Thomson, 1997a, 1997b; Murphy et al., 1997, 1998; Silva and Prather, 1997; Thomson et al., 1997; Murphy and Schein, 1998)	Particle sizes and single particle compositions.	Particles in air are introduced into successively lower-pressure regions and acquire high velocities due to gas expansion. Particle size is evaluated by laser light scattering. The particles then enter a time-of-flight mass spectrometer.
<b>Ambient Carbon Particulate Monitor (ACPM)</b> <sup>y</sup> (Turpin et al., 1990a, 1990b; Chow et al., 1993a; Rupprecht et al., 1995)	Concentrations of organic and elemental carbon. Detection limit ~ 0.2 µg/m <sup>3</sup> for a two hour average.	Measurement of carbon particulate by automatic thermal CO <sub>2</sub> method. The carbon collected in a high-temperature impactor oxidized at elevated temperatures after sample collection is complete. A CO <sub>2</sub> meter measures the amount of carbon released as result of sample oxidation. OC and EC can be speciated by volatilizing OC at an intermediate temperature.
<b>Sulfur Analyzer, Flame Photometric Detection (FPD)</b> <sup>k,ag</sup> (Dagnall et al., 1967; Stevens et al., 1969, 1971; Farwell and Rasmussen, 1976; Cobourn et al., 1978; Durham et al., 1978; Huntzicker et al., 1978; Kittelson et al., 1978; Jaklevic et al., 1980; Mueller and Collins, 1980; Tanner et al., 1980; Camp et al., 1982; Benner and Stedman, 1989, 1990)	Sulfur dioxide and sulfate. Detection limit ~ 0.1 µg/m <sup>3</sup> for a one hour average.	Sulfur species are combusted in a hydrogen flame, creating excited sulfur dimers (S <sub>2</sub> *). Fluorescence emission near 400 nm is detected by a photomultiplier. The photomultiplier current is proportional to the concentration of sulfur in all species. Four out of five FPD systems agreed to within ± 5% in a one-week ambient sampling intercomparison.

**Table 9.1-1 (continued)**  
**Summary of Continuous Monitoring Technology**

<u>Instrument</u>	<u>Quantity Measured</u>	<u>Methodology</u>
<b>Nitrate Analyzer, Automated Particle Nitrate Monitor (APNM)</b> <sup>a,y,ag</sup> (Winkler, 1974; Roberts and Friedlander, 1976; Hering and Friedlander, 1982; Stein et al., 1994; Yamamoto and Kosaka, 1994; Hering, 1997; Chow and Watson, 1998b; Chow et al., 1998b; Hering, 1998; Hering and Stolzenburg, 1998; Norton et al., 1998)	Particle Nitrate. Detection limit ~ 0.5 µg/m <sup>3</sup> for a 12-minute average.	Particle collection by impaction followed by flash vaporization and detection of the evolved gases in a chemiluminescent NO <sub>x</sub> analyzer.
<b>Streaker</b> <sup>w</sup> (Hudson et al., 1980; Bauman et al., 1987; Annegarn et al., 1990; Chow, 1995)	PM <sub>2.5</sub> and PM <sub>10</sub> elemental composition.	Particles are collected on two impaction stages and a Nuclepore polycarbonate-membrane after-filter followed by particle-induced x-ray emission (PIXE) analysis for multielements.
<b>Davis Rotating-Drum Universal-Size-Cut Monitoring Impactor (DRUM)</b> <sup>ac</sup> (Raabe et al., 1988; Pitchford and Green, 1997)	Size-fractionated elemental composition from 0.07 µm to 15 µm in diameter for eight size ranges.	Particles are collected on grease-coated mylar substrates that cover the outside circular surface of eight clock-driven slowly rotating cylinders or drums (one for each stage). Mylar substrates are submitted for focused-beam particle-induced x-ray emission (PIXE) analysis of multielements.
<b>VI. Precursor Gas Monitors</b>		
<b>Ammonia Analyzer, Chemiluminescence</b> <sup>z</sup> (Breitenbach and Shelef, 1973; Braman et al., 1982; Keuken et al., 1989; Langford et al., 1989; Wyers et al., 1993; Sorensen et al., 1994; Chow et al., 1998b; Jaeschke et al., 1998)	Ammonia concentration. Detection limit ~ 10 ppb.	Ammonia concentrations are measured by first removing oxides of nitrogen, then oxidizing ammonia to nitrogen oxide by thermal oxidation at high temperature for detection by chemiluminescence.
<b>Ammonia Analyzer, Fluorescence</b> <sup>b,q</sup> (Abbas and Tanner, 1981; Rapsomanikis et al., 1988; Genfa et al., 1989; Harrison and Msibi, 1994)	Ammonia concentration. Detection limit ~ 0.1 ppb.	Sampled ammonia is removed from the airstream by a diffusion scrubber, dissolved in a buffered solution, and reacted with o-phthalaldehyde and sulfite. The resulting i-sulfonatatoisindole fluoresces when excited with 365 nm radiation, and the intensity of the 425 nm emission is monitored for quantification. The diffusion scrubber might be modified to pass particles while excluding ammonia gas to continuously quantify ammonium ions.

**Table 9.1-1 (continued)**  
**Summary of Continuous Monitoring Technology**

<u>Instrument</u>	<u>Quantity Measured</u>	<u>Methodology</u>
<b>Other ammonia analyzers<sup>ag</sup></b> (Appel et al., 1988; Rooth et al., 1990; Wiebe et al., 1990; Williams et al., 1992; Sauren et al., 1993; Schendel et al., 1990; Platt, 1994; Mennen et al., 1996)	Ammonia concentration.	Other, less established methods to measure ammonia include photoacoustic spectroscopy, vacuum ultraviolet/photofragmentation laser-induced fluorescence, Differential Optical Absorption Spectroscopy (DOAS) in the ultraviolet Differential Absorption Lidar (DIAL, see section 3.2.5), and Fourier Transform Infrared (FTIR) spectroscopy (see section 3.6.3).
<b>Nitric Acid Analyzer<sup>ag</sup></b> (Ripley et al., 1964; Kelly et al., 1979, 1990; Burkhardt et al., 1988; Fox et al., 1988; Hering et al., 1988; Fehsenfeld et al., 1990; Gregory et al., 1990; Harrison, 1994; Harrison and Msibi, 1994)	Nitric acid concentration. Detection limit ~ 0.1 ppb for a 5-minute average.	Nitric acid can be reduced to NO <sub>2</sub> prior to detection by the chemiluminescent and luminol methods.
<b>Long Path Fourier Transform Infrared Spectroscopy (FTIR)<sup>o</sup></b> (White, 1976; Tuazon et al., 1978; Doyle et al., 1979; Tuazon et al., 1980; Tuazon et al., 1981; Hanst et al., 1982; Biermann et al., 1988; Hanst and Hanst, 1994)	Nitric acid and ammonia concentrations. Detection limit ~ 4 ppb for nitric acid and ~ 1.5 ppb for ammonia for a 5-minute average.	Long path absorption spectroscopy. A path length of more than 1 km is folded into a 25-m long White cell.
<b>Tunable Diode Laser Absorption Spectroscopy (TDLAS)<sup>ab</sup></b> (Schiff et al., 1983; Anlauf et al., 1985, 1988; Harris et al., 1987; Fox et al., 1988; Hering et al., 1988; Mackay et al., 1988; Schmidtke et al., 1988; Fehsenfeld et al., 1998)	Nitric acid concentration. Detection limit ~ 0.3 ppb for a 5-minute average.	Nitric acid concentrations are measured by high spectral resolution diode laser spectroscopy in the mid-infrared spectral region. The sample is introduced into a reduced pressure White cell to reduce pressure broadening and increase the path length.
<b>Mist Chamber<sup>ag</sup></b> (Talbot et al., 1990)	Nitric acid concentrations. Detection limit ~ 0.01 ppb for a 10-minute average.	The mist chamber method samples nitric acid by efficiently scrubbing it from the atmosphere in a refluxing mist chamber followed by analysis of the scrubbing solution for NO <sub>3</sub> <sup>-</sup> by ion chromatography. A sensitivity of 10 pptv for a 10-minute integration period has been reported.

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**Table 9.1-1 (continued)**  
**Summary of Continuous Monitoring Technology**

<u>Instrument</u>	<u>Quantity Measured</u>	<u>Methodology</u>
<b>Laser-Photolysis Fragment-Fluorescence (LPFF)<sup>ag</sup></b> (Papenbrock and Stuhl, 1991)	Nitric acid concentrations. Detection limit ~ 0.1 ppb for a 15-minute average.	Nitric acid concentrations have also been measured with the Laser-Photolysis Fragment-Fluorescence (LPFF) Method, which irradiates the air sample with ArF laser light (193 nm) resulting in the photolysis of nitric acid. The resulting hydroxyl radical (OH) emits fluorescence at 309 nm which is taken as a measure of the nitric acid mixing ratio in air. A sensitivity of 0.1 ppbv and a time constant of 15 minutes limited by surface ad- and desorption have been reported. An intercomparison of this technique with a denuder technique was also reported.
<b>Chemical Ionization Mass Spectrometry (IMS)<sup>ag</sup></b> (Huey et al., 1998; Mauldin et al., 1998; Fehsenfeld et al., 1998)	Nitric acid concentrations. Detection limit ~ 0.005 ppb for a 10-second average.	Chemical Ionization Mass Spectrometry (CIMS) has been used for the sensitive (few pptv) and fast (second response) measurement of atmospheric nitric acid concentrations. Reagent ions formed by an ion source are mixed with the sampled air and react selectively with nitric acid. The ionic reaction product is detected with a mass spectrometer. Two different CIMS instruments have been described and compared with an older, more established filter pack technique.

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**Table 9.1-1 (continued)**  
**Summary of Continuous Monitoring Technology**

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**Table 9.1-1 (continued)**  
**Summary of Continuous Monitoring Technology**

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**Table 9.1-2.**  
**Operating Characteristics of Commercially Available Nephelometers.**

<u>Manufacturer</u>	<u>Model</u>	<u>Scattering Type</u>	<u>Sampling</u>	<u>Time Resolution</u>	<u>Center Wavelength</u>	<u>Backscatter Feature</u>
Belfort	1590	Integrating	Forced	2 min	530 nm	No
Optec	NGN-2	Integrating	Passive	≥ 2 min	550 nm	No
TSI	3551	Integrating	Forced	≥ 2 sec	550 nm	No
TSI	3563	Integrating	Forced	≥ 2 sec	450, 550, and 700 nm	Yes
Radiance	M903	Integrating	Forced	≥ 10 sec	530 nm	No
Grimm	DustCheck	Sideways	Forced	≥ 3 sec	780 nm	No
MIE	DataRam	Forward	Forced	≥ 1 sec	880 nm	No
MIE	personal DataRam	Forward	Passive	≥ 1 sec	880 nm	No
Met One Instruments	GT-640	Forward	Forced	≥ 1 min	781 nm	No
R&P	DustLite Model 3000	Forward	Forced	≥ 3 sec	880 nm	No
TSI	DustTrack Model 8520	Sideways	Forced	≥ 1 sec	780 nm	No

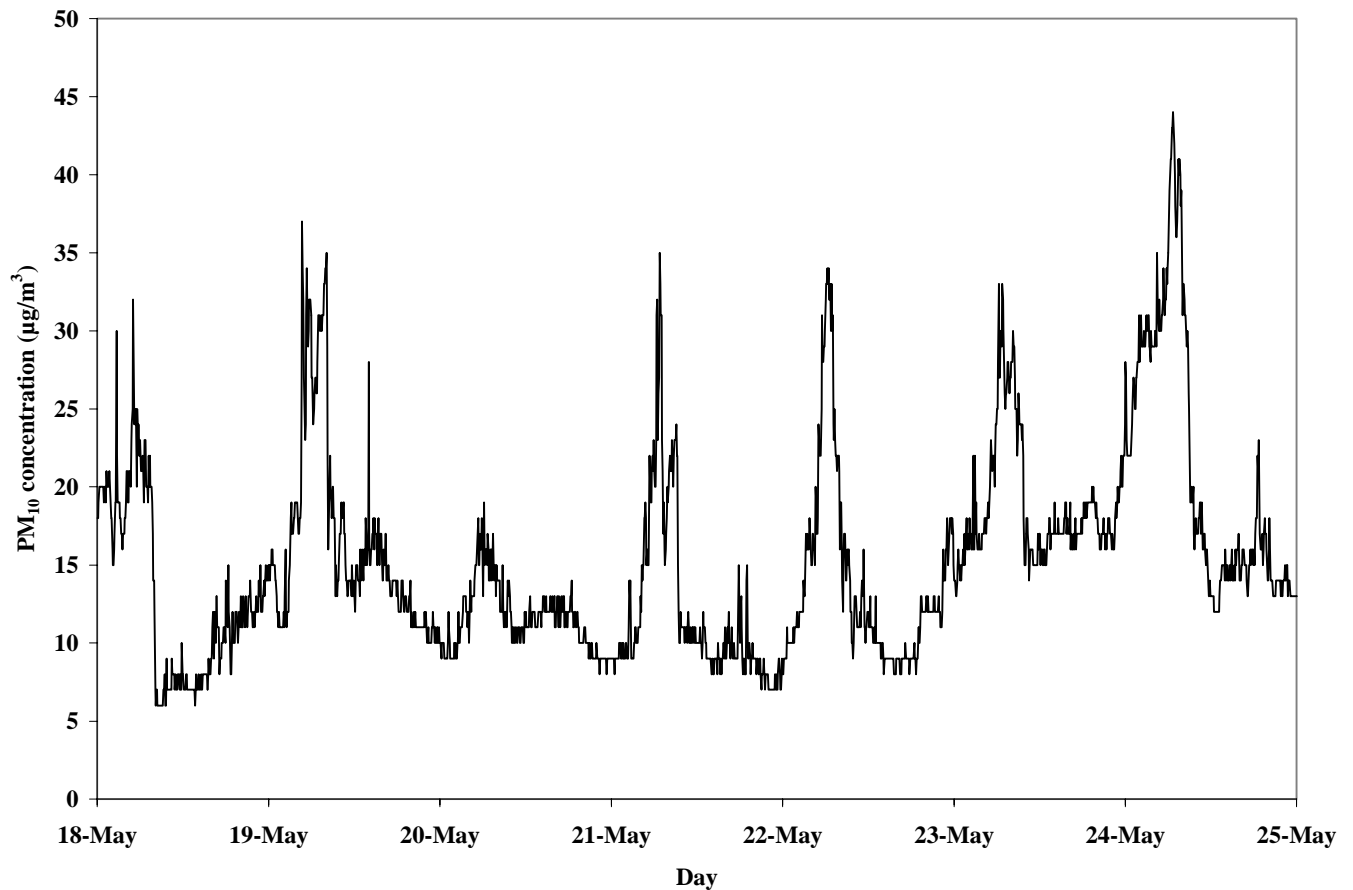
**Table 9.2-2.**  
**Minimum Detectable Limits for Different Sample Durations and Flow Rates.**

<u>Species</u>	<u>Method</u>	<u>Analysis LQL</u>	<u>Norm</u>	<u>Vol (ml)</u>	<u>LQL (ug/liter)</u>	<u>Lower Quantifiable Limits (ug/m<sup>3</sup>)</u>				
						<u>3-hour</u>		<u>24-hour</u>		
						<u>16.7 L/min</u>	<u>55 L/min</u>	<u>110 L/min</u>	<u>5 L/min</u>	<u>16.7 L/min</u>
Mass	Gravimetry	15 ug/filter	NA	NA	15	4.9900	1.5152	0.7576	2.0833	0.6238
Chloride	IC	0.05 ug/ml	2	10.0	1.50	0.4990	0.1515	0.0758	0.2083	0.0624
Nitrate	IC	0.05 ug/ml	2	10.0	1.50	0.4990	0.1515	0.0758	0.2083	0.0624
Sulfate	IC	0.05 ug/ml	2	10.0	1.50	0.4990	0.1515	0.0758	0.2083	0.0624
Ammonium	AC	0.05 ug/ml	2	10.0	1.50	0.4990	0.1515	0.0758	0.2083	0.0624
Soluble Potassium	AA	0.07 ug/ml	2	10.0	2.10	0.6986	0.2121	0.1061	0.2917	0.0873
Nitric Acid (as NO <sub>3</sub> <sup>-</sup> )	IC	0.05 ug/ml	1	5.0	0.25	0.0832	0.0253	0.0126	0.0347	0.0104
Ammonia (as NH <sub>4</sub> <sup>+</sup> )	AC	0.05 ug/ml	1	5.0	0.25	0.0832	0.0253	0.0126	0.0347	0.0104
SO <sub>2</sub> (as SO <sub>4</sub> <sup>-</sup> )	IC	0.05 ug/ml	1	10.0	1.25	0.4158	0.1263	0.0631	0.1736	0.0520
Total OC	TOR	0.82 ug/cm <sup>2</sup>	13.8	NA	11.3	3.7645	1.1430	0.5715	1.5717	0.4706
Total EC	TOR	0.19 ug/cm <sup>2</sup>	13.8	NA	2.62	0.8723	0.2648	0.1324	0.3642	0.1090
Al	XRF	0.0025 ug/cm <sup>2</sup>	13.8	NA	0.138	0.0459	0.0139	0.0070	0.0192	0.0057
Si	XRF	0.0014 ug/cm <sup>2</sup>	13.8	NA	0.0869	0.0289	0.0088	0.0044	0.0121	0.0036
P	XRF	0.0014 ug/cm <sup>2</sup>	13.8	NA	0.0773	0.0257	0.0078	0.0039	0.0107	0.0032
S	XRF	0.0012 ug/cm <sup>2</sup>	13.8	NA	0.0690	0.0230	0.0070	0.0035	0.0096	0.0029
Cl	XRF	0.0026 ug/cm <sup>2</sup>	13.8	NA	0.138	0.0459	0.0139	0.0070	0.0192	0.0057
K	XRF	0.0015 ug/cm <sup>2</sup>	13.8	NA	0.0842	0.0280	0.0085	0.0043	0.0117	0.0035
Ca	XRF	0.0011 ug/cm <sup>2</sup>	13.8	NA	0.0621	0.0207	0.0063	0.0031	0.0086	0.0026
Ti	XRF	0.00073 ug/cm <sup>2</sup>	13.8	NA	0.0400	0.0133	0.0040	0.0020	0.0056	0.0017
V	XRF	0.00062 ug/cm <sup>2</sup>	13.8	NA	0.0345	0.0115	0.0035	0.0017	0.0048	0.0014
Cr	XRF	0.00048 ug/cm <sup>2</sup>	13.8	NA	0.0262	0.0087	0.0026	0.0013	0.0036	0.0011
Mn	XRF	0.0004 ug/cm <sup>2</sup>	13.8	NA	0.0221	0.0073	0.0022	0.0011	0.0031	0.0009
Fe	XRF	0.00038 ug/cm <sup>2</sup>	13.8	NA	0.0207	0.0069	0.0021	0.0010	0.0029	0.0009
Co	XRF	0.00022 ug/cm <sup>2</sup>	13.8	NA	0.0121	0.0040	0.0012	0.0006	0.0017	0.0005
Ni	XRF	0.00022 ug/cm <sup>2</sup>	13.8	NA	0.0123	0.0041	0.0012	0.0006	0.0017	0.0005
Cu	XRF	0.00027 ug/cm <sup>2</sup>	13.8	NA	0.0152	0.0050	0.0015	0.0008	0.0021	0.0006
Zn	XRF	0.00027 ug/cm <sup>2</sup>	13.8	NA	0.0152	0.0050	0.0015	0.0008	0.0021	0.0006
Ga	XRF	0.00048 ug/cm <sup>2</sup>	13.8	NA	0.0262	0.0087	0.0026	0.0013	0.0036	0.0011

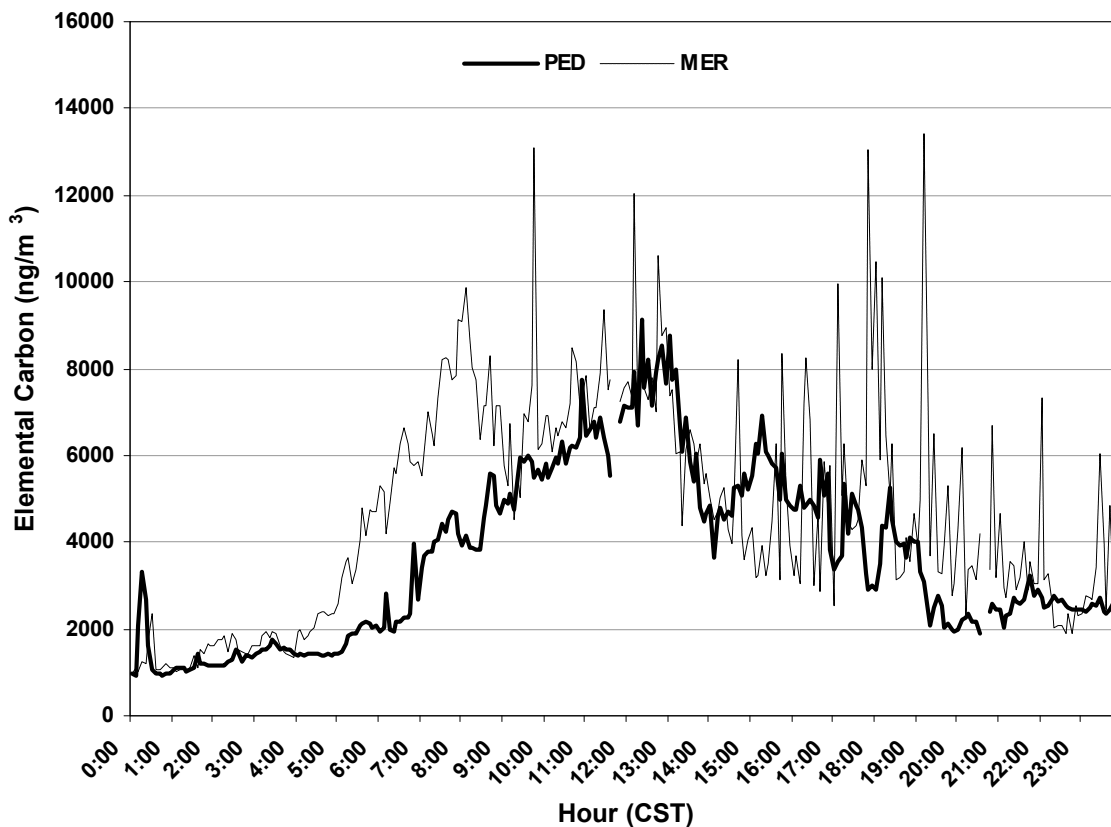


**Table 9.2-2.**  
**Minimum Detectable Limits for Different Sample Durations and Flow Rates.**

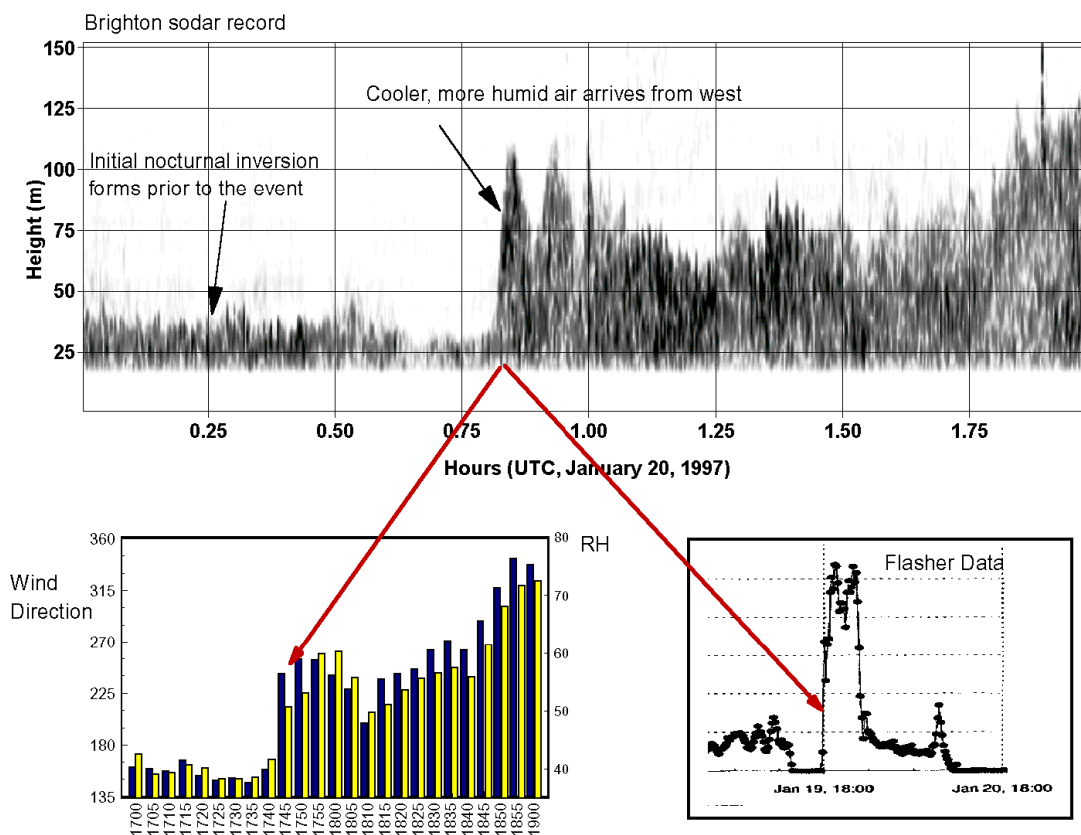
<u>Species</u>	<u>Method</u>	<u>Analysis LQL</u>	<u>Norm</u>	<u>Vol (ml)</u>	<u>LQL</u> <u>(ug/fiter)</u>	<u>Lower Quantifiable Limits (ug/m<sup>3</sup>)</u>				
						<u>3-hour</u>		<u>24-hour</u>		
						<u>16.7 L/min</u>	<u>55 L/min</u>	<u>110 L/min</u>	<u>5 L/min</u>	<u>16.7 L/min</u>
As	XRF	0.00039 ug/cm <sup>2</sup>	13.8	NA	0.0221	0.0073	0.0022	0.0011	0.0031	0.0009
Se	XRF	0.00031 ug/cm <sup>2</sup>	13.8	NA	0.0166	0.0055	0.0017	0.0008	0.0023	0.0007
Br	XRF	0.00025 ug/cm <sup>2</sup>	13.8	NA	0.0138	0.0046	0.0014	0.0007	0.0019	0.0006
Rb	XRF	0.00024 ug/cm <sup>2</sup>	13.8	NA	0.0138	0.0046	0.0014	0.0007	0.0019	0.0006
Sr	XRF	0.00028 ug/cm <sup>2</sup>	13.8	NA	0.0152	0.0050	0.0015	0.0008	0.0021	0.0006
Y	XRF	0.00033 ug/cm <sup>2</sup>	13.8	NA	0.0179	0.0060	0.0018	0.0009	0.0025	0.0007
Zr	XRF	0.00042 ug/cm <sup>2</sup>	13.8	NA	0.0235	0.0078	0.0024	0.0012	0.0033	0.0010
Mo	XRF	0.00067 ug/cm <sup>2</sup>	13.8	NA	0.0373	0.0124	0.0038	0.0019	0.0052	0.0015
Pd	XRF	0.0027 ug/cm <sup>2</sup>	13.8	NA	0.1518	0.0505	0.0153	0.0077	0.0211	0.0063
Ag	XRF	0.003 ug/cm <sup>2</sup>	13.8	NA	0.1656	0.0551	0.0167	0.0084	0.0230	0.0069
Cd	XRF	0.003 ug/cm <sup>2</sup>	13.8	NA	0.1656	0.0551	0.0167	0.0084	0.0230	0.0069
In	XRF	0.0034 ug/cm <sup>2</sup>	13.8	NA	0.1794	0.0597	0.0181	0.0091	0.0249	0.0075
Sn	XRF	0.0044 ug/cm <sup>2</sup>	13.8	NA	0.2346	0.0780	0.0237	0.0118	0.0326	0.0098
Sb	XRF	0.0045 ug/cm <sup>2</sup>	13.8	NA	0.2484	0.0826	0.0251	0.0125	0.0345	0.0103
Ba	XRF	0.0130 ug/cm <sup>2</sup>	13.8	NA	0.7176	0.2387	0.0725	0.0362	0.0997	0.0298
La	XRF	0.0160 ug/cm <sup>2</sup>	13.8	NA	0.8556	0.2846	0.0864	0.0432	0.1188	0.0356
Au	XRF	0.00077 ug/cm <sup>2</sup>	13.8	NA	0.0428	0.0142	0.0043	0.0022	0.0059	0.0018
Hg	XRF	0.00065 ug/cm <sup>2</sup>	13.8	NA	0.0359	0.0119	0.0036	0.0018	0.0050	0.0015
Tl	XRF	0.00062 ug/cm <sup>2</sup>	13.8	NA	0.0345	0.0115	0.0035	0.0017	0.0048	0.0014
Pb	XRF	0.00076 ug/cm <sup>2</sup>	13.8	NA	0.0414	0.0138	0.0042	0.0021	0.0058	0.0017
U	XRF	0.00059 ug/cm <sup>2</sup>	13.8	NA	0.0317	0.0106	0.0032	0.0016	0.0044	0.0013



**Figure 9.1-1.** Five-minute average TSI DUSTTRAK nephelometer measurements at a residential site at a post office in Sparks, NV, between May 18 and May 25, 1998. An elevated PM spike is clearly seen in the morning hours. The sharp peaks indicate contributions from nearby emitters superimposed over wider peaks that indicate aggregate sources such as morning rush-hour traffic.



**Figure 9.1-2.** Five-minute-average aethalometer black carbon measurements at a downtown Merced (MER) site and a suburban Pedregal (PED) site in Mexico City on 3/10/97. The PED site is ~15 km south of the MER site, and prevailing afternoon winds are northwesterly. The short-term spikes correspond to contributions from very nearby sources, such as diesel exhaust plumes from trucks and buses. Morning traffic emissions buildup at the urban site can be seen as the increment over that at the suburban site. Concentrations are more uniform, when short-term spikes are disregarded, during the afternoon when vertical mixing and surface flows increase. A buildup at the MER site occurs after sunset at ~18:30 CST when a surface inversion sets in.



**Figure 9.1-3.** Illustration of automated flash volatilization nitrate measurements from the Northern Front Range Air Quality Study (Watson et al., 1998) in the lower right-hand panel. This shows a short-duration nitrate incursion at the non-urban Brighton site on 1/19/97. Time series of surface winds, sodar, and flash volatilization particle nitrate measurements are also shown. Air surged from the west along the Front Range. The initial microfront is seen in the sodar record as cooler air from the lower terrain to the west (along the South Platte River) surges eastward over the Brighton site.

## 10. METEOROLOGICAL MEASUREMENTS

Meteorological measurements at the surface and aloft are needed during all seasons to interpret the air quality measurements.

### 10.1 Surface Wind Speed and Direction

Wind speeds are measured with anemometers at 10 m above ground to minimize the effects of nearby structures and vegetation. Anemometers, both cup and propeller type, work on the principal that the rate of rotation about a vertical or horizontal shaft is proportional to the speed of the air flow past the sensor. Anemometers used for scientific monitoring should have a quick response to changes in wind speed as well as a low threshold for rotation for conditions of very light winds. Acceptable precision levels for anemometers are  $\pm 0.5$  m/s for most air quality studies (e.g., Thullier *et al.*, 1993), but even lower thresholds are needed for the CRPAQS wintertime study owing to the large number of calms that occur.

Wind direction measurements are made with wind vanes that orient themselves with the direction of the wind. High quality bearings are used for sensitivity and direction is resolved with an internal potentiometer that has a reference location of zero which must be physically aligned with true north when in position on the tower. The position of true north is determined with a sensitive compass or solar reference and the north position of the wind vane is then aligned in this direction. Care must be taken in the alignment procedure or in subsequent resolution of the wind direction vectors to account for the magnetic declination at the observation site.

Averaging can be done over intervals of a few points to the entire data record. The interval must be chosen with respect to the phenomena being observed. As shorter averaging intervals are chosen, periodic motion may be revealed when the period is significantly greater than the averaging period. The averaging process attenuates small-scale fluctuations due to turbulence. The averaging interval must contain sufficient data points to constitute a reasonable average, eliminating the small scale turbulent fluctuations and instrument derived errors such as response sensitivity and anemometer run-up and run-down. Five minutes is a reasonable compromise between the need to acquire a statistically valid number of samples and the nature of phenomena such as wind gusts and dispersion.

The time average of horizontal wind direction standard deviation ( $\sigma_\theta$ ) can be calculated as from one second observations over a period of 5 minutes or less (Greeley and Iversen, 1985). This minimizes the influence of the wind flow which may be non-stationary in both speed and direction over longer averaging periods.

Table 10.1-1 provides specifications for CRPAQS wind sensors. Instruments meeting these specifications were used in the Southern California Ozone Study (SCOS 97) (Fujita *et al.*, 1997) and the Northern Front Range Air Quality Study (NFRAQS) (Chow *et al.*, 1998). SCOS-97 performance audits were satisfactory with  $\pm 0.25$  m/s for wind speeds between 0 and 5 m/s, and  $\pm 5\%$  for wind speeds greater than 5 m/s. The NFRAQS intercomparison of meteorological sensors concluded that from collocated instruments were comparable to each other at the 95%

confidence level when sampling the same environment. NFRAQS and SCOS-97 also demonstrated a high level of instrument functionality, with few episodes of missing data at any of the seven monitoring sites.

## **10.2 Surface Relative Humidity**

Humidity indicates the amount of water vapor in the air. The most common reference for this property of the air is the relative humidity (RH), the ratio of the amount of water vapor actually in the air to the amount the air could hold at a given temperature and pressure, that is, the ratio of the actual to the saturated vapor pressure.

Accurate measurements at high RH (>85%) is important to atmospheric transformations and to visibility reduction. An accuracy of 2-3% RH is needed to adequately estimate aerosol properties. A 2-3% accuracy for RH over the 90-100% RH is attainable by several RH sensors (e.g. Vaisala, Rotronics) and corresponds to  $\pm 0.5^{\circ}\text{C}$  when expressed as dewpoint temperature. Motor-aspirated radiation shields ensure adequate ventilation and exposure rates (U.S. EPA, 1989).

## **10.3 Surface Temperature**

Equivalent resistance temperature detectors (RTD (e.g., Vaisala, Rotronics, Climatronics, Campbell Scientific, etc.) are used at the meteorological sites. Motor-aspirated radiation shields ensure adequate ventilation and exposure rates, according to U.S. EPA quality assurance requirements (U.S. EPA, 1989). The accuracy ( $\sim 0.15\text{-}0.5^{\circ}\text{C}$ ) and functional precision ( $0.1^{\circ}\text{C}$ ) of these sensors are sufficiently good and they can be used to infer lapse rates and thus stability (e.g., estimates of  $\Delta T$ ) when several sensors are used on a tower. Temperature sensors are normally located at 5 m above ground level. Table 10.1-1 presents specifications for the Vaisala and Campbell Scientific (CV) temperature ( $^{\circ}\text{C}$ ) and relative humidity (%) sensors

## **10.4 Surface Pressure**

Pressure is routinely measured by the National Weather Service in terms of altimeter setting or sea level pressure. The altimeter setting is the pressure value to which an aircraft altimeter scale is set so it will indicate the altitude above mean-sea-level of the aircraft on the ground at the location the pressure value was determined. The sea level pressure is the atmospheric pressure at mean sea level. It is either measured directly or obtained by the empirical reduction of station pressure to sea level. When the earth's surface is above sea level, it is assumed that the atmosphere extends to sea level below the station and that the properties of the fictitious air column are related to conditions observed at the station.

## **10.5 Solar Radiation**

Solar radiation sensors are operated at several existing ARB sites throughout the region. The measurements employ a solar pyranometer that collects direct solar beam and diffuse sky radiation passing through a horizontal beam.

## 10.6 Upper-Air Wind Speed, Wind Direction, and Temperature

Upper-air wind speed, wind direction, and temperature can be collected by *in-situ* systems or by remote sensing instruments. The most commonly used *in-situ* systems rely on a balloon-borne sensor (radiosonde), carried aloft by a freely ascending weather balloon to measure atmospheric pressure, temperature, and moisture (relative humidity or wet bulb temperature). These thermodynamic variables are used to compute the altitude of the balloon. Wind speed and direction aloft are determined by measuring the position of the balloon as it ascends. The position data can be obtained by tracking the balloon from a fixed ground station using radio direction finding techniques (RDF) or optical tracking, or they can be obtained using one of the radio navigation (NAVAID) networks, such as loran or Global Positioning System (GPS). By measuring the position of the balloon with respect to time and altitude, horizontal wind vectors can be computed that represent the layer-averaged wind speed and wind direction for successive layers. Balloons can also measure relative humidity, which is not detected by proven remote sensing methods.

The vertical resolution of the wind data is typically 50-200 m (depending on altitude and the type of sounding system used), and the range is from about 100 m above ground level (AGL) to altitudes as high as 10,000 m altitude or higher. For air pollution studies such as this, balloon sounding systems can provide relatively complete profiles of winds, temperature, and moisture in the boundary layer and lower troposphere. Balloon soundings usually can be made two to eight times per day on selected sampling days within reasonable budget constraints, but they are not cost-effective for long-term monitoring.

The tetheredsonde system uses a small helium-filled, blimp-shaped balloon to carry aloft a radiosonde that is equipped with sensors to measure the thermodynamic variables listed above as well as sensors to measure wind speed and wind direction. The tetheredsonde can be used to continuously profile the lower atmosphere (up to about 500-1,000 m above ground level, depending on wind conditions and FAA restrictions) by raising and lowering the balloon using a winch. The main drawbacks to the tetheredsonde system are the costs to operate it (it must be manned continuously while operating) and restrictions on how high it can ascend.

Remote sensing systems include: 1) 915 MHz radar wind profilers equipped with radio acoustic sounding systems (RASS) for temperature profiling, and 2) Doppler acoustic sounders (sodar) for aloft wind measurements. Radar profilers and sodars both use the principle of the Doppler effect to measure winds aloft. The radar profiler transmits an electro-magnetic signal and the sodar transmits an acoustic signal along each of three beams: one aimed vertically to measure atmospheric vertical velocity, and the other two aimed at oblique angles off vertical and oriented orthogonal to each other to measure the horizontal components of the air's motion.

Small-scale turbulence in the atmosphere scatters part of the transmitted signals back to the instruments, where the data acquisition and signal processing systems determine the Doppler shift of the returned (back-scattered) energy. By measuring the Doppler shift of the air motion along all three components, horizontal wind speeds and directions as a function of altitude can be computed. Profilers and sodars operate continuously, with wind profiles typically computed for 30-60 minute averaging intervals. Radar profilers can measure winds with 60-100 meter vertical

resolution from approximately 100 m above ground level to altitudes as high as 4-5 km. Doppler sodars can measure winds aloft with 30-50 m vertical resolution from approximately 50-500 meters above ground level. With the addition of a RASS, the radar profiler can also measure vertical profiles of temperature (actually virtual temperature) from about 100 m to 1,000-1,500 m above ground level, again with a vertical resolution of 60-100 meters.

It is also possible to combine a Doppler sodar with a Radio Acoustic Sensing System (RASS), where the RASS acoustic signals can be provided by the sodar and the radar profiler requires only a vertically-pointing antenna. For sodar-RASS combinations with a conventional three-axis or phased-array sodar, the altitude performance (range, resolution) for wind sampling will be the same as for a stand-alone sodar. Altitude coverage for RASS is lower than that of a radar profiler-RASS combination unless the strength of the acoustic signal generated by the sodar can be increased to levels higher than normally used for wind sampling. The maximum altitude obtained for wind and temperature sampling using a “mega” sodar-RASS combination may be higher. Costs for such a system are comparable to or higher than a radar profiler and RASS. The nuisance effects due to the noise produced by these systems, especially from a mega sodar, may be substantial.

Balloon-borne sounding systems can provide data with sufficient accuracy, range, and resolution (spatial) to meet the data objectives of the study. In addition, they provide vertical profiles of atmospheric moisture, which cannot presently be measured by remote sensing systems. The principle drawback to in-situ sounding systems is the cost to obtain the data and their inability to provide the temporal resolution one can obtain with remote sounding systems. These systems can be set up easily, and are good for short-term studies, but they are more costly to operate routinely with high sounding frequencies than are the continuous remote systems.

Radar profilers equipped with RASS can also provide wind and temperature data with the accuracy, range, and resolution needed to meet the data objectives of the study. In addition, they provide continuous measurements of winds and temperature, and of returned power, which can be used to infer mixing depth. Their principle drawbacks are that they do not measure atmospheric moisture, and there are interferences created by radar clutter targets (e.g., trees, power lines, migrating birds, etc.) that can reduce data recovery rates under certain circumstances. However these interferences can be partially offset by exercising proper siting procedures.

Doppler sodars can provide wind data with the accuracy and resolution required for the study. Their sampling range is limited to the first few hundred meters of the atmosphere, which may not be adequate to provide data over the full range required to monitor the transport of pollutants in the study area. “Mega” sodars are still experimental, and to our knowledge commercial systems are not yet routinely operational or reliable. The performance characteristics of “mega” sodars (e.g., range, resolution, accuracy, precision, etc.) are not yet proven. Unlike profilers, temperature measurements using RASS with sodars are also not yet proven and reliable. Acoustic signal interferences that may limit data recovery are created by clutter sources, noise sources, and high winds.



Based on these considerations, the CRPAQS relies mostly on 915 MHz radar profilers and RASS because these methods can make continuous measurements over the altitude range of greatest interest. The RASS provides temperature profiles from which stability, inversions depths, and plume rise can be inferred, and because the system will provide continuous data with minimal maintenance compared to *in-situ* systems. The profilers are supplemented during winter with sodars that can measure to lower levels and better capture the dynamics of mixing between the surface layer and the higher valleywide layer, especially during late morning, early afternoon, and after sunset. Owing to their logistical requirements and cost, airsondes are used only during wintertime episodes to evaluate winds at very high elevations and to document the vertical structure of relative humidity.

## 10.7 Fogs and Cloud

Fogs and clouds are important in creating particles and as vehicles for particle removal. Ideally, the droplet number, droplet size, liquid water content (LWC) and chemical content of fogs and clouds would be measured to determine the chemistry associated with plume conversion. The current technology for such measurements is limited with respect to feasibility, practicality, and accuracy.

The measurement of the liquid water content of the atmosphere (LWC) near the earth's surface can be accomplished with several different methodologies. However, the methodologies that have previously been used do not measure the absolute quantity of liquid water in the air. Hering et al. (1987) provide an operational parameter based on an instrument response. At present, there is a significant problem in assessing different techniques because there is no accepted standard method for the determination of LWC. Collecting fog or cloud water for determination of mass of water per unit volume of air and its chemical composition is a difficult measurement problem. Fog has a range of droplet sizes from 1-100  $\mu\text{m}$  creating problems for collection efficiency as well as problems of segregation from other aerosols of similar physical and chemical properties.

Hering et al. (1987) describe several methods for fog measurement, but these methods are being supplanted by more modern techniques. Newly developed fog particle samplers are being tested in the Davis, CA area during the winter of 1999, and results from these tests will be evaluated.

**Table 10.4-1**  
**Meteorological Sensor Specifications**

Sensor	Accuracy	Range	Response Time	Sensitivity	Stability	Error
<b>AIR db Pr</b>	±0.7 mb	600-1100 mb	ms-range	.01 mb		
<b>CS207 T</b>	±0.4 °C	-33 - +48°C				<0.1 °C linear error
<b>CS207 RH</b>	± 5 %	0 - 100 %				<±3.0 %
<b>CS500 T</b>	±0.4 ±0.6	-40 - +60 °C				
<b>CS500 RH</b>	±2% @ 0-90% ±3% @ 90-100%	0 - 100 %			±1%/yr	
<b>Li-Cor 200SA Solar</b>	Within 95-98% of Eppley standard	.15-3.0 µm	10 µs	80 µA per 1000 Wm <sup>-2</sup>	<±2%/yr	Abs error: ±5% of Eppley
<b>REBS Net Rad</b>		.25-60 µm	30 s			
<b>RM Young Speed</b>	±.25 m/s, ws: 0-5 m/s ±5%, ws >5 m/s	0-60 m/s 100 m/s (peak gust)		0.9 m/s		
<b>RM Young Direction</b>	±5 Deg	0-355 Deg electrical		1 m/s @ 10° displ.		
<b>Vaisala T</b>	±0.4 °C	-35 - +50 °C				
<b>Vaisala RH</b>	±2% @ 0-90% ±3% @ 90-100%	0 - 100 %	15 s		1%/yr	

## 11. DATA MANAGEMENT AND VALIDATION

The CRPAQS data base will be compiled, documented, evaluated, and distributed by the Technical Support Division of the Air Resources Board (ARB). Common data management and validation conventions need to be assembled in a consistent and efficient manner. These conventions are described in this section. This section will be updated with more specific conventions and reporting structures after CRPAQS measurement investigators have been commissioned and provided their suggestions and recommendations. To the greatest extent possible, CRPAQS field data structures, processing, validation, and delivery procedures will be consistent with those established for the long-term data base and other ARB data sets from recent air quality studies (e.g. Fujita et al., 1997).

### 11.1 Data Specifications

CRPAQS data management conventions and methods build on experience from and development supported by the 1990 San Joaquin Valley Air Quality Study (SJVAQS) (Blumenthal et al., 1993), the 1995 Integrated Monitoring Study (IMS-95) (Solomon and Magliano, 1997), and the 1997 Southern California Oxidant Study (SCOS-97) (Fujita et al., 1997). The following specifications are maintained by the data manager and are available to all project participants via the internet:

- **Measurement locations:** Each measurement location is identified with a unique alphanumeric site ID accompanied by its name and address, coordinates, elevation, its primary operator, and a summary of measurements taken at the site for different monitoring periods. Appendices A-D summarizes existing and proposed field study measurement locations. Coordinates and elevations are verified by the field manager with a Global Positioning System (GPS), pressure-based altimeter, and topographical maps. Immediate surroundings are recorded with a digital camera and a video tape of the area surrounding the site is available and catalogued. The make and model of instruments used to acquire measurements at each site is recorded with its threshold, range, expected accuracy and precision.
- **Variable definitions:** Each variable is assigned a unique code that is accompanied by its definition, units, averaging time, applicable temperature and pressure adjustments, and data reporting format.
- **Data validation flags:** Flags specific to each measurement investigator are translated into a common set of validation flags that are carried with each data point. These are currently being defined by EPA for its speciation program, and this will be a starting point for CRPAQS data validation flags.
- **Data files:** Basic data files are constructed in normalized formats that have the same structure for different types of data. These files will be transparent to most users.

- **Timing conventions:** Times are expressed in Pacific Standard Time (PST), hour or minute beginning. All dates as MM/DD/YYYY (note that years are four-digit codes: 1999, 2000, 2001).
- **Missing data conventions:** Missing or invalid measurements are replaced by a -99 or a "NULL" value if the data management software permits.
- **Investigator code:** Each measurement investigator or network operator is assigned a unique two-character code that is used to identify the source of the data. Data transmittals will carry this code as part of the filename when they are loaded into a raw data sub-directory, and a separate sub-directory on the CRPAQS internet server.

## 11.2 Data Formats

Data acquired at set intervals are submitted as comma delimited text files via file transfer protocol to the sub-directory set up for each measurement investigator. File naming conventions are given below. Raw data file naming conventions include the investigator code, a measurement type code, and an indicator for the period of data acquisition. Formats are:

- **Continuous sequential measurements:** SSSS, MM/DD/YY, HHMM, TIME, DURATION, PARAM1, RESULT, QCFLAG, PARAM2, RESULT, QCFLAG,
- **Surface particle measurements:** SSSS, MM/DD/YY, HHHMM, TIME, DURATION, SIZE, PARAM1, RESULT, QCFLAG, PARAM2, RESULT, QCFLAG
- **Upper air measurements:** SSSS, MM/DD/YY, HHMM, TIME, EV\_MSL, PARAM1, RESULT, QCFLAG, PARAM2, RESULT, QCFLAG

The mnemonics have the following definitions:

- **SSSS** = 3 - 4 character project site ID code
- **MM/DD/YYYY** = date specification
- **HHMM**=standard sample start time, begin hour and minutes PDT (0000-2355)
- **TIME** = actual sample start time, HHMMSS
- **DURATION** = sampling in total minutes
- **EV\_MSL** = elevation in meters above mean sea level
- **PARAM** = project parameter code
- **SIZE** = 1 letter particle size category (e.g. T = PM<sub>10</sub> (0-10 µm); F = Fine(0-2.5 µm); C =Coarse (2.5-10 µm); S=sum of Fine+Coarse ~ PM<sub>10</sub>; P = TSP (0-30 µm), and other particle size ranges as needed)
- **RESULT** = data value in project specified significant digits
- **QCFLAG** = 1 character project QC code indicating quality of data point

### 11.3 File Names

File names are of the form CDDMMYYA.PLL

- **C**=investigator code (**to be defined**)
- **DD** =data type code (**to be defined**)
- **MM** = month code (JA,FE,MR,AP,MY,JN,JL,AU,SE,OC,NO,DE)
- **YYYY** = Year code
- **A** = Averaging interval codes: (A = 3 hour; B = 6 hour; C = 12 hour; D= 24 hour ;H = 1 hour; J = jumps (every other hour); V = hourly but varies, possibly less than 24 measurements per day; I = Instantaneous ( < 1 min); F=5 minute; T=10 minute; M = 15 minute; N=30 minute; P = Partial hour samples (< 60 min)
- **P** = Measurement platform code (S = surface, U = upper air)
- **LL** = Two character data validation level code (OA,OB,1A,1B,2A,2B,3A).

### 11.4 Validation Flags

Procedure- and investigator-specific validation flags will be maintained in a separate validation file. These must be translated into the common flags listed below. A translation table will be established as part of the database that associates each investigator flag with one of the following flags: 0=valid; 1 = estimated; 2=calibration; 3=instrument failure; 4=off-scale reading; 5 = interpolated; 6=below detection limits; 7=suspect; 8=invalid; 9=missing; a=hourly avg (45 <->60 minutes); b=hourly avg (<45 minutes); d=averaged data; e=zero mode; and f=blank sample

### 11.5 Data Validation Levels

Mueller (1980), Mueller et al., (1983), and Watson et al. (1983, 1989, 1995) define a three-level data validation process that should be mandatory in any environmental measurement study. Data records are designated as having passed these levels by entries in the VAL column of each data file. These levels, and the validation codes that designate them, are defined as follows:

- **Level 0 (0):** These data are obtained directly from the data loggers that acquire data in the field. Averaging times represent the minimum intervals recorded by the data logger, which do not necessarily correspond to the averaging periods specified for the data base files. Level 0 data have not been edited for instrument downtime, nor have procedural adjustments for baseline and span changes been applied. Level 0 data are not contained in the CRPAQS database, although they are consulted on a regular basis to ascertain instrument functionality and to identify potential episodes prior to receipt of Level 1A data.

- **Level 1A (1A):** These data have passed several validation tests applied by the measurement investigator prior to data submission. The general features of Level 1A are: 1) removal of data values and replacement with -99 when monitoring instruments did not function within procedural tolerances; 2) flagging measurements when significant deviations from measurement assumptions have occurred; 3) verifying computer file entries against data sheets; 4) replacement of data from a backup data acquisition system in the event of failure of the primary system; 5) adjustment of measurement values for quantifiable baseline and span or interference biases; and 6) identification, investigation, and flagging of data that are beyond reasonable bounds or that are unrepresentative of the variable being measured (e.g. high light scattering associated with adverse weather).
- **Level 1B (1B):** Pre-programmed consistency and reasonability tests are applied by the data manager prior to integration into the CRPAQS data base. Consistency tests verify that file naming conventions, data formats, site codes, variable names, reporting units, validation flags, and missing value codes are consistent with project conventions. Discrepancies are reported to the measurement investigator for remediation. When the received files are consistent, reasonability tests are applied that include: 1) identification of data values outside of a specified minimum or maximum value; 2) values that change by more than a specified amount from one sample to the next; and 3) values that do not change over a specified period. Data identified by these filters are individually examined and verified with the data supplier. Obvious outliers (e.g. high solar radiation at midnight, 300 °C temperature) are invalidated. Others may be invalidated or flagged based on the results of the investigation. The bounds used in these tests will be determined in cooperation with measurement investigators and network operators..
- **Level 2 (2):** Level 2 data validation takes place after data from various measurement methods have been assembled in the master database. Level 2 validation is the first step in data analysis. Level 2A tests involve the testing of measurement assumptions (e.g. internal nephelometer temperatures do not significantly exceed ambient temperatures), comparisons of collocated measurements (e.g. filter and continuous sulfate and absorption), and internal consistency tests (e.g. the sum of measured aerosol species does not exceed measured mass concentrations). Level 2 tests also involve the testing of measurement assumptions, comparisons of collocated measurements, and internal consistency tests.
- **Level 3 (3):** Level 3 is applied during the model reconciliation process, when the results from different modeling and data analysis approaches are compared with each other and with measurements. The first assumption upon finding a measurement which is inconsistent with physical expectations is that the unusual value is due to a measurement error. If, upon tracing the path of the measurement, nothing unusual is found, the value can be assumed to be a valid result of an environmental cause. The Level 3 designation is applied only to those variables that have undergone this re-examination after the

completion of data analysis and modeling. Level 3 validation continues for as long as the database is maintained.

A higher validation level assigned to a data record indicates that those data have gone through, and passed, a greater level of scrutiny than data at a lower level. All data in the CRPAQS data set will achieve Level 1B status prior to use in data analysis and modeling. The validation tests passed by Level 1B data are stringent by the standards of most air quality and meteorological networks, and few changes are made in elevating the status of a data record from Level 1B to Level 2. Since some analyses are applied to episodes rather than to all samples, some data records in a file will achieve Level 2 designation while the remaining records will remain at Level 1B. Only a few data records will be designated as Level 3 to identify that they have undergone additional investigation. Data designated as Levels 2 or 3 validations are not necessarily “better” than data designated at Level 1B. The level only signifies that they have undergone additional scrutiny as a result of the tests described above.

## 11.6 Internet Server

CRPAQS data and communications will be received and made available on the Internet server <http://sparc2.baaqmd.gov/centralca/> maintained by the Bay Area Air Quality Management District. This server currently contains project documentation and will be developed to contain project status during field monitoring and project data as it becomes available.

## 11.7 Directory Structure

Data and communications files are organized into several sub-directories within the CRPAQS server. Each of these contains additional sub-directories to further organize the information. This organization will be transparent to most users who will access information through links available through browsing software. All directories, with exception of the TEMP directory and its sub-directories, have read-only privileges for most users to avoid the inadvertent erasure of information. Files may be uploaded to investigator-specific sub-directories in the TEMP directory for later placement in the appropriate read-only directory by the data manager. These CRPAQS directories are:

- **TEMP:** This is a temporary location where files are uploaded by project participants prior to their transfer to their designated parent directory. An e-mail message should be sent to the data manager indicating the uploaded file name and its desired directory location. The TEMP directory is also used to allow the transfer of non-archived scratch files among project participants.
- **REPORTS:** This directory contains files related to project reports, memoranda, and minutes. Sub-directories are:
  - PROGPN for the latest draft of the program and management plans
  - MEMO for project memoranda
  - MINUTES for minutes of discussions
  - NOTICES for meeting notices

- PRGREG for progress reports
- RFP for final versions of requests for proposals
- **RAWDATA:** This directory contains data files in the form they are received from the data source. These files are in several different formats, cover different time periods, and do not necessarily conform to the units and variable naming conventions adopted for CRPAQS field studies. To conserve disk space, these files are usually backed up onto storage media after they have been processed; they can be re-loaded upon request to the data manager. They are located in directories specific to each data supplier, as specified in the next section.
- **DATA:** This directory contains validated ambient measurement data in data management formats that have been converted to common units and variable names.
- **QA:** This directory contains quality assurance results from audits, performance tests, and collocated measurements.
- **TABLES:** This directory contains tables of processed results, including statistical summaries of data, frequency distributions, and data capture rates. These are made available via html links through the CRPAQS home page.
- **FIGURES:** This directory contains figures of processed results, including time series, spatial isopleth plots, cumulative frequency plots, and scatterplot comparisons. These are made available via html links through the CRPAQS home page.
- **MAPS:** This directory contains base maps of terrain, highways, population centers, political boundaries, land use, and surface characteristics in formats that are deemed useful for different analyses.
- **UTILITIES:** This directory contains software created for the project, software available for distribution for which licenses have been obtained, and commonly used shareware. These include data conversion, format conversion, file compression, and data display programs. These are made available via html links through the CRPAQS home page.

Other directories and sub-directories are created as needed to organize the information produced by CRPAQS field studies.

## 11.8 Data Processing

Data are submitted by each investigator using the defined variable naming conventions and units. All values are to be at Level 1A when submitted. These are passed through the Level 1B tests described above, and discrepancies are resolved with the measurement investigator and corrected prior to designation as Level 1B. Data are added to the master data files as they are received.

Measurements from other ongoing networks described in Section 4 are acquired in formats and units specific to those networks. Data processing functions are specific to these



networks and have been established during the compilation of the multi-year database for central California. First, these files are manually edited, when needed, because they sometimes contain minor variations in format that confound the data conversion programs. After editing, a network-specific data conversion program reads the data and converts it to an xBase file format with a single record for each measurement. Variable names in these intermediate file differ from those in CRPAQS files by designating the unit used for each measurement in the specified network. For example, field name “TA\_\_F” indicates ambient temperature in degrees Fahrenheit as found in the NWS database rather than the “TA” field name for ambient temperature in degrees Celsius that is used in the CRPAQS data files.

The next step converts measurement units to the CRPAQS common units. Conversion factors are accessed from a file that maps one unit into another based on the specification of the input and output variable names. In addition to changing units, the conversion program maps times, dates, missing values, and validation flags into the CRPAQS conventions described above.

A data validation log is kept to document all changes made to the data files, including changes in the data validation level. This includes a record of the data changed, the reason for the change, and the date of the change. All data as originally submitted to the database are retained so that changes can be traced back to the original data.

## 12. QUALITY ASSURANCE

Every measurement consists of a value, a precision, an accuracy, and a validity. Quality control (QC) and quality auditing establish the precision, accuracy, and validity of measured values. Quality assurance integrates quality control and quality auditing to determine these four attributes of each environmental measurement. Quality assurance (QA) is a project management responsibility that integrates quality control, quality auditing, measurement method validation, and sample validation into the measurement process. The results of quality assurance are data values with specified precisions, accuracies, and validities. Quality auditing is performed by personnel who are independent of those performing the procedures, and an independent quality assurance officer will be retained early in the planning phases to plan, and coordinate CRPAQS field study QA activities. Performance testing and quality auditing methods will be developed with CRPAQS measurement investigators and network operators and summarized in this section. The section currently provides general guidance on the activities to be performed. CRPAQS quality assurance will identify and correct deficiencies promptly at the beginning of and during the measurement period. It will also document and quantify data quality for the benefit of data analysts and modelers.

Quality control (QC) is the responsibility of each investigator. Quality control is intended to prevent, identify, correct, and define measurement difficulties and to provide the quality control test data needed to quantify the precision, accuracy, and validity of the data. The QC activities include: 1) modifying standard operating procedures (SOPs) and other project documentation to be followed during ambient and source sampling, analysis, and data processing; 2) equipment overhaul, repair, acceptance testing, and spare parts; 3) operator training, supervision and support; 4) periodic calibrations and performance tests which include blank and replicate analyses; and 5) quality auditing.

As part of the QC function, each investigator will provide a precision, accuracy, and validity to be reported with each value in the database. Each investigator will also prepare a data quality summary that will, in a few pages, summarize the completeness, accuracy, precision, and lower quantifiable limits for each type of measurement.

The quality auditing function consists of two components: 1) systems audits and 2) performance audits. Systems audits start with a review of the operational and QC procedures to assess whether they are adequate to assure valid data which meet the specified levels of accuracy and precision. After reviewing the procedures, the auditor examines all phases of the measurement or data processing activity to determine that the procedures are being followed and the operational people are properly trained. The systems audit is intended to be a cooperative assessment resulting in improved data, rather than a judgmental activity.

Performance audits establish whether the predetermined specifications are being achieved in practice. The performance audit challenges the measurement/analysis system with a known standard sample which is traceable to a primary standard. For data processing, the performance audit consists of independently processing sections of the data and comparing the results.

## 12.1 Quality Assurance Documentation

Overall guidance for quality assurance in this study will follow the recommendations of the North American Research Strategy for Tropospheric Ozone (NARSTO), as expressed in the following NARSTO quality assurance planning documents (<http://narsto.owt.com/Narsto/QSMP.html>):

- Quality Planning Handbook which provides overall quality planning guidance.
- Quality Systems Management Plan (QSMP), which is the first and highest level of NARSTO program quality assurance documents and is the umbrella under which all quality-related activities are to be planned and conducted.
- Data Management Handbook, which provides guidance concerning the management of data, products, and records.

The NARSTO guidance calls for two additional types of quality assurance documents to be prepared for each project:

- The Program Quality Management Plan (PQMP) is the second level of quality planning, and it describes the quality assurance activities and expectations for a particular study such as CRPAQS. The PQMP is comparable to the type of document that is often called a Quality Assurance Project Plan. For this study, the PQMP will be prepared by the CRPAQS Project Manager, with substantial assistance from the quality assurance manager.
- The Quality Integrated Work Plan (QIWP), at the third level of documentation, is prepared by each measurement investigator to define the data quality objectives and activities associated with each type of measurement.

SOPs provide even further details on the specific operations of the measurements by codifying the actions which are taken to implement a measurement process over a specified time period. State-of-the-art scientific information is incorporated into the SOP with each revision. SOPs include the following elements:

- A brief summary of the measurement method, its principles of operation, its expected accuracy and precision, and the assumptions which must be met for it to be valid.
- A list of materials, equipment, reagents, and suppliers. Specifications are given for each expendable item.
- Designation of the individual to be responsible for each part of the procedure.
- A general traceability path, the designation of primary standards or reference materials, tolerances for transfer standards, and a schedule for transfer standard verification.

- Start-up, routine, and shut-down operating procedures and an abbreviated checklist.
- Copies of data forms with examples of filled out forms.
- Routine maintenance schedules, maintenance procedures, and troubleshooting tips.
- Internal calibration and performance testing procedures and schedules.
- External performance auditing schedules.
- References to relevant literature and related standard operating procedures.

Standard operating procedures needed for CRPAQS field studies are identified in Table 12.1-1. These SOPS are available in electronic form on the CRPAQS internet server.

## **12.2 Field Audits**

Table 12.2-1 lists the performance objectives for instruments on which field performance audits are conducted. Table 12.2-2 specifies frequencies and standards for calibration, performance tests, and field audits. Field audits provide an independent check of operating status and measurement accuracy. Audit findings are compared against measured values to decide whether or not remedial action is needed. Some of the methods that can be used to evaluate compliance with performance objectives are summarized below. These methods will be refined and modified in cooperation with measurement investigators.

### **12.2.1 Wind Speed and Direction**

The wind direction system challenge consists of a sensor orientation test, a sensor bearing check, and an evaluation of sensor siting and exposure. The orientation test is performed by siting the vane to and from two landmarks. The orientation of these landmarks is derived by using solar siting, a magnetic compass, or topographic map. The bearings are checked using a torque wheel.

The wind speed system audit includes testing the system output at three designated wind speed values and zero, checking the sensor bearings, and evaluating the sensor siting and exposure. The sensor is spun using a multiple speed motor, converting the revolutions per minute of the motor to equivalent wind speed and then comparing this designated speed to the system output speed. The sensor bearings are tested using a torque wheel.

### **12.2.2 Solar Radiation**

Auditing the solar radiation system consists of collocating a certified reference pyronometer with the on-site sensor and comparing the output of the reference sensor to the on-site system output. The sensor siting is also checked for proper exposure.

### **12.2.3 Barometric Pressure**

Auditing of the barometric pressure is performed by collocating a certified reference pressure sensor with the on-site sensor. The output of the reference sensor is compared against the system response as displayed on the data logger. The sensor siting is also checked.

### **12.2.4 Temperature and Relative Humidity**

The temperature and relative humidity measurement systems audit is performed by collocating a certified reference temperature/relative humidity system equipped with its own aspirator and data logger. The filter element of both the audit system and the station sensor is replaced with a slotted filter to increase the response time of both sensors. The filter of the station sensor is also checked for contamination. The audit system output is compared to the station system response. Sensor siting and exposure are also checked. Methods need to be perfected that verify relative humidity measurements under high humidity conditions.

### **12.2.5 Nephelometer**

Nephelometers are audited by performing a zero and upscale calibration using the built-in calibration system, performing a zero and upscale calibration using the audit calibration system, comparing the audit calibration to the station calibration to assess the validity of operator-performed calibrations, and comparing the audit calibration to the installation calibration to assess how the instrument has changed since installation.

The nephelometer light trap and zero air filter are examined to see if they have been contaminated with water. The lamp output intensity is verified as is the time and date of the data logger. The built-in zero/span system is verified. Following the zero/span check, the on-site span gas cylinder is replaced with the audit cylinder (DuPont SUVA-134a refrigerant) and the zero air filter is replaced with the audit filter. A zero/span check is then performed using the audit standards and the analog and serial responses recorded. The on-site gas standard and zero air filter is reinstalled and a final zero/span check performed and the serial and analog output recorded. The results of the final zero/span check are then compared to the results of the audit check.

### **12.2.6 Aethalometer**

The aethalometer measurement of absorption is evaluated by inserting neutral density filters of known light transmission into the sample path. Flow rates are verified against an audit standard.

### **12.2.7 Particle Filter Samplers**

Sampler flow rates are measured and recorded using the on-site flow meter and the flow rates recorded. The flow rates are then measured using the audit flow meter and the two responses compared. At the time of the audit, the barometric pressure and ambient temperature are recorded and the readings are corrected to standard reference conditions. Total flow rate is checked to see that it meets the required flow for the specified inlet cut point. The systems are

also leak checked by measuring the total flow through the inlet and verifying that it equals the total flow as measured through the filter system. The elapsed timers are checked for proper operation and the time and date as displayed on the system clock verified against the audit watch.

### **12.2.8 High Sensitivity Sulfur Dioxide Analyzer**

Zero gas and then four known low concentrations of SO<sub>2</sub> and the responses are recorded. The concentrations are 5, 10, 15, 20, and 40 ppb SO<sub>2</sub> delivered by a portable mass flow controlled gas dilution unit and a certified gas cylinder. These are lower than those usually applied for compliance-oriented sulfur dioxide monitoring.

### **12.2.9 Radar Profiler, SODAR, RASS**

Collocated sodars and rawinsondes at several sites can be used for performance audits. If additional performance audits are needed, sodars and/or rawinsondes may be used. If rawinsondes are used, at least 3 soundings covering the diurnal cycle should be taken. If sodars are used, the sodars should be configured to match the RWP data in temporal and spatial averaging as much as possible. The sodars should be run for at least 24 hours, and data compared to the RWP data while on-site. Comparisons between sodars and rawinsondes and RWP should be done when winds are at least 2 ms<sup>-1</sup>.

The radiosonde data is linearly interpolated to the midpoint of each vertical slice sampled by the profiler and the data is then compared by computing the difference between the profiler data and radiosonde data (bias). Bias is computed only for levels for which the profiler collects valid wind speed and direction data, and only for levels where the radiosonde indicates wind speeds of at least 2.0 m/s. Wind speeds less than 2.0 m/s are considered calm and therefore are not included in the bias calculations.

Bias for the RASS is calculated by computing the difference between the RASS temperature and the temperature measured by the radiosonde at the midpoint of the vertical slice sampled by the RASS. Only those levels for which the RASS returns valid data are included in the bias calculation. Note that, like the wind profiler, the RASS signal may be contaminated by the Doppler shift generated as a result of vertical winds. Temperature data reported by the RASS are virtual temperatures, and radiosonde temperature data are converted to virtual temperature using the measured ambient temperature, relative humidity, and pressure.

The following instrument tests are completed as part of the audit:

- The antenna and controller interface cables are inspected for proper connection. When multi-axis antennas are used, this includes verifying the proper direction of the interface connections.
- Orientation of individual antennas or phased-array antenna using solar sitings where possible. The measured orientation of the antennas should be compared with the system software settings. The antenna alignment should be maintained within  $\pm 2^\circ$ . For multi-axis antennas, the inclination angle, or zenith angle from the vertical,

should be verified against the software settings and the manufacturer's recommendations. The measured zenith angle should be within  $\pm 0.5^\circ$  of the software settings in the data system. For phased-array antennas, and for the vertical antenna in a multi-axis system, the level of the antenna should be within  $\pm 0.5^\circ$  of the vertical.

- For multi-axis sodar systems, a separate distinct pulse, or pulse train in the case of frequency coded pulse systems, should be heard from each of the antennas. In a frequency-coded pulse system, there may be a sound pattern that can be verified. The instrument manual should be checked to see if there is such a pattern.
- For sodar systems, general noise levels are measured, in dBA, to assess ambient conditions and their potential influence on the altitude capabilities of the sodar. In general, levels below 50 dBA indicate a quiet site, while levels above 60 dBA are quite noisy. The altitude coverage of the sodar will be directly related to the ambient noise at the site.
- The antenna enclosures should be inspected for structural integrity that may cause failures as well as any sign of debris or animal or insect nests that may cause drainage problems in the event of rain or snow.
- The time clocks on the data acquisition systems should be checked and compared to a standard of  $\pm 2$  minutes.

#### **12.2.10 Radiosondes**

Performance audits of rawinsondes are of little value because the instruments (radiosondes) are used only once. Representative of each batch of sondes received from the manufacturer should be acceptance tested with respect to temperature, relative humidity, and specified transmission frequencies prior to field distribution. The site operator will verify each sonde against an in-station hygrometer prior to launch, and the auditor will verify that these records exist and compare the hygrometer with standards. The auditor will observe an entire launch cycle at each site, checking: 1) ground station initialization; 2) sonde initialization; 3) balloon inflation; 4) radio theodolite's antenna orientation using solar sightings; 5) data acquisition; 6) data archiving and backup; and 7) flight termination.

#### **12.3 Laboratory Audit and Comparisons**

Laboratory performance audits consists of the submission of known standards to routine laboratory procedures and of an interlaboratory comparison of those standards. To audit the analysis of soluble species, a solution containing chloride, sulfate, sodium, nitrate, ammonium, and potassium is prepared and deposited in known amounts on quartz-fiber filters. Samples at three concentrations are submitted to the routine chemical analyses for chloride, nitrate, and sulfate by ion chromatography, for water-soluble potassium by atomic absorption spectrophotometry, and for ammonium by automated colorimetry. To audit the analysis of the elements by XRF or PIXE, six thin film Micromatter pure-element deposits are submitted for routine XRF analysis.

At the present time there are no widely accepted standards for elemental and organic carbon. Potassium acid phthalate (KHP) solutions are deposited on quartz-fiber filters to create organic carbon standards. Three concentrations are produced. Three sets of analyses at each concentration level and three blank filters are analyzed for total carbon. Gravimetric analysis is audited by weighing independent Class M weights and Teflon filters which will be pre-weighed and post-weighed at the analysis and at the audit laboratory for comparison.

One laboratory intercomparison will be conducted during the study. The laboratory intercomparison takes place during the middle of chemical analyses for this project.

#### **12.4 Corrective Actions**

Findings from the field audits are communicated to the field coordinator and the responsible measurement investigator immediately upon their recognition. A system for remedial action is devised and implemented. This is especially important for the first audits when difficulties are often recognized as a result of recent installation. Laboratory audits and comparisons should be done early in the analysis program to identify deficiencies that might be corrected.



**Table 12.1-1**  
**Summary of CRPAQS Standard Operating Procedures**

Subject	Observable/ Method	Standard Operating Procedure (SOP) Title
<b>I. FIELD OPERATIONS</b>		
Meteorology	Wind Speed Wind Direction Sigma Theta Temperature Relative Humidity	Operation and Maintenance of Meteorological Instruments
Air Quality	PM <sub>2.5</sub> PM <sub>2.5</sub> PM <sub>2.5</sub> , PM <sub>10</sub>	FRM Sequential Filter Sampler Field Operations Minivol Sampler Field Operations TEOM Field Operation
<b>II. LABORATORY OPERATIONS</b>		
Sample Preparation	Filter Pack Assembly and Disassembly	Filter Pack Assembly and Disassembly, Filter Sectioning, and Filter Storage
Chemical Analysis	PM <sub>2.5</sub> , PM <sub>10</sub> Mass Elements Nitrate (NO <sub>3</sub> <sup>-</sup> ) Sulfate (SO <sub>4</sub> <sup>2-</sup> ) Ammonium (NH <sub>4</sub> <sup>+</sup> )  Soluble Potassium (K <sup>+</sup> )  Organic Carbon Elemental Carbon	Teflon Filter Inspection and Weighing Analysis of Teflon Membrane Filters by X-Ray Fluorescence Analysis of Filter Extracts and Precipitation Samples by Ion Chromatography Analysis of Filter Extracts and Precipitation Samples by Automated Colorimetry Analysis of Filter Extracts and Precipitation Samples by Atomic Absorption Spectroscopy Analysis of Filter Deposits by Thermal/Optical Carbon Analysis
<b>III. DATA PROCESSING/DATA VALIDATION</b>		
Particle Data	PM <sub>2.5</sub> Chemical Compositions	Field, Mass, and Chemical Data Processing and Data Validation for PM <sub>10</sub> Data
Continuous Data	Meteorological Data	Meteorological Data Processing and Data Validation
<b>IV. FIELD AUDITING</b>		
Aerosol Samplers	Sample Volumes	Systems and Performance Audit Procedures for Filter-Based Particle Monitors

**Table 12.1-1**  
**Summary of CRPAQS Standard Operating Procedures**

Subject	Observable/ Method	Standard Operating Procedure (SOP) Title
Surface Meteorological Stations	Wind speed, direction, temperature, relative humidity	Systems and Performance Audit Procedures for Instrumented Meteorological Towers
<b>V. LABORATORY AUDITING</b>		
XRF	Selected elemental concentrations	Systems and Performance Audit Procedures for X-Ray Fluorescence Analysis
Interlaboratory Comparisons	Selected chemical concentrations	Interlaboratory Comparison Sample Exchange and Evaluation Protocol

**Table 12.2-1.**  
**CRPAQS Performance Audit Minimum Accuracy Goals.**

<u>Parameter</u>	<u>Accuracy</u>
<b>FIXED PLATFORM METEOROLOGY</b>	
Horizontal Wind Speed	$\pm (0.2 \text{ mps} \pm 5 \text{ percent of observed})$
Horizontal Wind Direction	$\pm 5.0 \text{ compass degrees}$
Temperature	$\pm 1.0 \text{ degrees Centigrade}$
Relative Humidity	$\pm 5\% \text{ difference}$
Solar Radiation	$\pm 5\% \text{ of observed (or } 50 \text{ watts/m}^2\text{)}$
Barometric Pressure	$\pm 3 \text{ millibars}$
<b>AIR QUALITY MONITORS</b>	
Sample Flow	$\pm 10\% \text{ of observed}$
Nephelometer	$\pm 15\% \text{ of observed or } 5 \text{ counts}$
MiniVol Sample Flow	$\pm 15\% \text{ of observed}$
Aethalometer Sample Flow	$\pm 10\% \text{ of observed}$
High Resolution Sulfur Analyzer	To be determined
<b>UPPER AIR METEOROLOGY</b>	
Radar Profiler Wind Speed	$\pm 3 \text{ mps}$
Radar Profiler Wind Direction	$\pm 20 \text{ compass degrees}$
RASS Virtual Temperature	$\pm 3 \text{ degrees Centigrade}$

**Table 12.2-2  
Field and Laboratory Performance Objectives, Test Frequencies, and Standards**

Observable	Measurement Device	Performance Test Frequency	Performance Standard	Calibration Frequency	Calibration Standard	Audit Frequency	Audit Standard	Primary Standard
<b><u>Aerosol</u></b>								
Sample Flow/ ±5%	PM <sub>2.5</sub> FRM	Once/week	Calibrated Rotameter	At the beginning and end of 12-month sampling period or when performance tests out of spec	Calibrated Rotameter	Twice/15-months	Mass Flow Meter	Certified Roots Meter
Sample Flow/ ±10%	Portable PM <sub>2.5</sub> Survey Sampler	Once/week	Built in Rotameter	At the beginning and end of 12-month sampling period or when performance tests out of spec	Portable Bubble Meter	Twice/15-months	Mass Flow Meter	Brooks Vol-u-met traced to NBS-Bubble Meter
Inlet Flow/ ±5%	PM <sub>2.5</sub> FRM Sequential Filter Sampler	Once/3-month	Calibrated Rotameter	At the beginning and end of 12-month sampling period or when performance tests out of spec	Calibrated Rotameter	Twice/15-months	Mass Flow Meter	Certified Roots Meter
PM <sub>2.5</sub> Mass	Cahn 31 Electromicro-balance	1/10 Samples	NBS Class M Standard Weights	At beginning of weighing session	NBS Class M Standard Weights	Once/15-months	NBS Class M Standard Weights	NBS Class M Standard Weights
b <sub>abs</sub>	Densitometry	1/10 Samples	Neutral Density Filters	At beginning of each session	Neutral Density Filters	Once/15-months	Neutral Density Filters	Neutral Density Filters
PM <sub>2.5</sub> Elements	KeveX 0700/8000 XRF Analyzer	1/15 Samples	NBS Thin Film Standards	Quarterly	Micromatter Thin Film Standards	Once/15-months	Prepared Standard Deposit	Thin Film Standard

**Table 12.2-2**  
**Field and Laboratory Performance Objectives, Test Frequencies, and Standards**

Observable	Measurement Device	Performance Test Frequency	Performance Standard	Calibration Frequency	Calibration Standard	Audit Frequency	Audit Standard	Primary Standard
<b><u>Aerosol (continued)</u></b>								
Soluble PM <sub>2.5</sub> Sulfate, Nitrate, and Chloride	Dionex 4000i Ion Chromatographic Analyzer	1/10 Samples	Solution Standards	At beginning of each run	ACS Certified Standard Solutions	Once/15-months	Spiked Filters Standard Solutions	ACS Certified Chemicals
Soluble PM <sub>2.5</sub> Potassium	Perkin-Elmer Model 2380 Atomic Absorption	1/10 Samples	Solution Standards	At beginning of each run	ACS Certified Standard Solutions	Once/15-months	Spiked Filters Standard Solutions	ACS Certified Chemicals
Soluble PM <sub>2.5</sub> Ammonium	Technicon TRAACS 800 Colorimetric Analyzer	1/10 Samples	Solution Standards	At beginning of each run	ACS Certified Standard Solutions	Once/15-months	Spiked Filters Standard Solutions	ACS Certified Chemicals
PM <sub>2.5</sub> Organic and Elemental Carbon	DRI/OGC Thermal/Optical Carbon Analyzer	1/10 Samples	Methane Gas	Bi-annually	Methane, CO <sub>2</sub> Gas and ACS Certified KHP	Once/15-months	Standard KHP and Sucrose Solutions	ACS Certified Chemicals
<b><u>Meteorology</u></b>								
Wind Speed	Anemometer	Weekly	Visually check anemometer rotation, compare observed wind speed and recorded value	None	None	Twice/15-months	Constant RPM motor	Yearly factory recertification

**Table 12.2-2**  
**Field and Laboratory Performance Objectives, Test Frequencies, and Standards**

Observable	Measurement Device	Performance Test Frequency	Performance Standard	Calibration Frequency	Calibration Standard	Audit Frequency	Audit Standard	Primary Standard
<b><u>Meteorology (continued)</u></b>								
Wind Direction Vane	Vane	Weekly	Visually check wind vane direction and compare value with recorded value	Quarterly	Alignment with true north determined by magnetic compass	Twice/15-months	Alignment with true north determined by magnetic compass	Magnetic Compass
Sigma Theta	Computed by DAS	Weekly	Visual check of range and variation	Quarterly	Frequency Generator	Twice/15-months	Frequency Generator	Frequency Counter
Temperature	Thermister	Weekly	Thermometer	Monthly	NBS-traceable Thermometer	Twice/15-months	Sling Psychrometer with NBS-traceable thermometer	NBS-traceable Thermometer
Relative Humidity	Lithium Strip Chloride Cell	Quarterly	Psychrometer	Semiannual	Assman Psychrometer	Twice/15-months	Sling Psychrometer with NBS-traceable thermometer	NBS-traceable Thermometer

## **13. RESPONSIBILITIES, SCHEDULE, AND BUDGET**

This section specifies the responsibilities of CRPAQS field study participants, budgets, and schedules.

### **13.1 Responsibilities**

The leadership roles in the CRPAQS field study include the principal investigators, the field coordinator, the quality assurance officer, the data manager, the measurement investigators, the CRPAQS technical committee, and the CRPAQS policy committee.

#### **13.1.1 Principal Investigators**

The principal investigators provide scientific and technical guidance for the California Regional PM<sub>10</sub>/PM<sub>2.5</sub> Air Quality Study. Specifically, the principal investigators will:

- Create initial study protocols for data analysis, modeling, emissions characterization, and field studies, and modify them in response to external evaluation and technical support study results.
- Assist in the preparation of work statements for complex project components.
- Critically review CRPAQS technical products and provide constructive recommendations for improvement and focus on CRPAQS goals and objectives.
- Keep informed of developments and findings in PM programs external to CRPAQS and incorporate that knowledge into CRPAQS planning and execution.
- Devise and refine conceptual models of elevated PM<sub>2.5</sub> and PM<sub>10</sub> in central California and assess the extent to which mathematical models simulate the physical and chemical mechanisms embodied in these concepts.
- Periodically integrate CRPAQS findings into summary reports and publications that are scientifically rigorous and policy-relevant.
- Disseminate CRPAQS scientific findings in scientific forums, national guidance documents, and peer-reviewed publications. Promote and facilitate the dissemination of specific research projects among other CRPAQS participants.

#### **13.1.2 Field Coordinator**

The field manager provides planning, support, and follow-up for the annual, winter, fall, and special studies. Specifically, the field coordinator will:

- Assist in field study planning, specifically keeping current the measurement locations, measurement methods, and quality assurance, schedule, and budget sections of this plan.
- Prepare work statements for different components of the field measurement program.
- Procure information needed to evaluate measurement method feasibility, practicality, and costs and make judgements concerning the costs vs. benefits of new measurement technology.
- Select sampling sites based on the monitoring purposes and criteria stated in this plan and document those sites with respect to their location and surroundings.
- Specify siting, electrical, communications and environmental requirements for each sampling site and procure the necessary permits, power, and security to operate those sites.
- Recruit, train (in collaboration with measurement investigators) and direct site operators. Monitor operator quality, in collaboration with measurement investigators, and take remedial actions where needed.
- Establish an efficient communications network, including a project roster of names, addresses, phone numbers, fax numbers, and e-mail addresses among other field study participants and apply that network to convey needed information among the participants.
- Participate in the evaluation of technical proposals from measurement investigators and provide perspective on the likelihood that different measurement alternatives to accomplish objectives.
- Identify and resolve communications difficulties among measurement investigators, the data manager, and the quality assurance officer to assure that audit findings are corrected and documented and that data flow efficiently and smoothly into the project database.
- Organize a forecasting team to determine the initiation and end of intensive operating periods during winter, develop a forecasting protocol, and implement it during the winter study. Develop a protocol to disseminate go/nogo and abort decisions.
- Document field study activities and accomplishments after its completion.
- Prepare a site report



### **13.1.3 Quality Assurance Officer**

The quality assurance officer provides direction, coordination, and documentation of measurement accuracy, precision, and validity. Specifically, the quality assurance officer will:

- Prepare a quality assurance program plan that specifies systems and performance auditing methods, intercomparison methods, primary and transfer standards, schedules, audit reporting formats, feedback to measurement investigators, and methods to verify that remedial actions have been taken.
- Assemble and direct a quality assurance team with specialized expertise and equipment in evaluating precision, accuracy, and validity of established and developing measurement methods. Deploy this team to conduct systems and performance audits, assemble the results, provide feedback to measurement investigators, and verify that remedial actions have been implemented.
- Analyze data from collocated or nearby air quality and meteorological measurement systems to estimate precision, equivalence, and predictability among measurements. Identify environmental and atmospheric composition conditions under which values for these attributes are acceptable and unacceptable.
- Identify, obtain, and evaluate standard operating procedures for methods to be applied during field studies.
- Evaluate data qualification statements prepared by measurement investigators.

### **13.1.4 Data Manager**

The data manager will establish and maintain computer-based data archives and communications. Specifically, the data manager will:

- Review and revise the data management section of this plan as changes are made to data reporting, structure, and retrieval conventions.
- Define and procure hardware and software needed to successfully complete the data management tasks.
- Prepare statements of work and direct data management support investigators to assist in the accomplishment of data management tasks.
- Establish a CRPAQS web page with links to: 1) long-term data archives; 2) electronic copies of CRPAQS reports and documents (electronic form); 3) CRPAQS participants' roster, roles, and websites (where available); and 4) standard operating procedures; 5) data receipt archives; 6) CRPAQS field study data archives; and 7) measurement sites and observables.

- Develop, apply, and document efficient and modern methods for receiving, processing, and delivering data from and to measurement, data analysis, and modeling investigators.
- Perform Level 1B validation tests. Apply Level II and III validation adjustments and flags.
- Transmit the final data base to the NARSTO data archive.

### **13.1.5 Measurement Investigators**

Measurement investigators are responsible for specialized CRPAQS measurements. Specifically, measurement investigators will:

- Specify and procure (or construct) monitoring devices and verify their adequacy for operation under conditions anticipated during CRPAQS field monitoring.
- Specify for the field coordinator space, power, sample presentation, supplies, storage, shipping/receiving, environmental, and communications requirements for each monitoring site at which the investigator's measurements will be acquired.
- Develop or adapt standard operating procedures and checklists and participate in training of site operators, or supply specially-trained site operators as needed.
- Install and calibrate instruments at the measurement sites and remove them after study completion.
- Supply expendables needed to maintain measurement schedules.
- Monitor network operations, in collaboration with the field coordinator, identify and remediate deficiencies.
- Evaluate and remediate system and performance audit findings and document that remediation.
- Regularly acquire raw measurements to evaluate monitor performance. Periodically reduce data, validate it at Level 1A, and deliver it in the prescribed formats to the data manager.
- Prepare a summary of monitoring methods, data and validation results, and measurement activities when measurements have been completed. Prepare data quality statements that evaluate the accuracy, precision, validity, and completeness of the measurements acquired during each phase of the field study.

### **13.1.6 Data Analysis and Modeling Investigators**

Data analysis and modeling investigators will use the integrated data set to perform Level 2 and Level 3 data validation, to further answer the questions posed in Section 3, and

to develop, evaluate, and apply source and receptor models. Several of the data analysis activities, especially those involved with determining Level 2 validation status of measurements and descriptive analysis of the measurements, are best performed by the measurement investigators. Specifically, data analysis and modeling investigators will:

- Evaluate the consistency of measurements, i.e. Level 2 validation.
- Describe statistical, temporal, and spatial distributions of measurements on average and during episodes.
- Interpret data to answer questions in Section 3.
- Recommend revisions to the conceptual models in Section 3, elaborating on the dominance and validity of chemical and physical mechanisms and the importance of different pollution sources.
- Use field measurements in meteorological and air quality source and receptor models to evaluate the extent to which they represent the identified mechanisms and emissions.
- Use field measurements to establish base cases for annual average and several different episodes of maximum concentration to evaluate the effects of different emissions reduction strategies.
- Identify data deficiencies and initiate Level 3 validation checks and corrections with the data manager.

#### **13.1.7 Technical Committee**

The technical committee is composed of scientific staff representatives from local, state, and federal regulatory agencies and private sector stakeholders. It provides overall technical direction to the project. Specifically, the technical committee will:

- Reviews each of the plans and recommends the final technical scope of each of these program elements.
- Prepare and disseminate requests for proposals for necessary work elements and evaluate the proposals received.
- Commission and evaluate CRPAQS technical reports and publications, including those relevant to field studies.
- Create and monitor overall project schedules and budgets, evaluate compromises between project needs and budget allocations, and institute remedial actions where needed.
- Institute, facilitate, and coordinate CRPAQS research activities with complementary activities sponsored by the local air quality management districts

(i.e. BAAQMD), California Air Resources Board, U.S. Environmental Protection Agency (Region IX, ORD, and OAQPS), the Department of Defense (Naval Weapons Center), Department of Agriculture, and industrial research sponsors (EPRI, CRC, WSPA, API).

- Participate in, to the extent possible, CRPAQS data acquisition, data analysis, and modeling activities.
- Disseminate CRPAQS scientific findings in scientific forums, national guidance documents, and peer-reviewed publications.

#### **13.1.8 Policy Committee**

The policy committee is composed of senior management representatives from local, state, and federal regulatory agencies and private sector stakeholders. It provides overall policy and financial direction to the project. Specifically, the Policy Committee will:

- Evaluate CRPAQS technical components for their relevance to future policy decisions and assure an adequate balance among those components.
- Monitor CRPAQS budgets, schedules, and product quality to assure fiduciary responsibility and fulfillment of commitments.
- Request, justify, and obtain sufficient sponsorship to complete defined activities that will achieve CRPAQS objectives.
- Review and evaluate policy-relevant CRPAQS findings, provide constructive recommendations for their expression, and convey these findings to stakeholders.

### **13.2 Schedule**

Table 13.2-1 provides milestones for CRPAQS field study and related activities. This schedule should be integrated with the master project schedule that includes emissions and modeling activities. This schedule will be maintained by the field coordinator and made more specific as planning progresses.

### **13.3 Costs**

Table 13.3-1 estimates costs associated with individual program elements. This table will be maintained by the field coordinator and made more specific as planning progresses.

**Table 13.2-1**  
**CRPAQS Field Study Schedule, 1998-2001**

Date	Cate gory	Activity	Primary Responsibility
Mar 98	F	Draft design and work statement for methods evaluation study	McDade
Apr98	F	Verify and update field study budgets. Finish bottom-up financial model	McDade
	F	Draft RSOQ for QA officer	McDade
	F	Draft work statement for data base upgrades	Niccum/Magliano
May 98	F	Field measurement workshop	Watson/McDade
	F	Revise field study plan	Watson/McDade
	F	Issue RFP(s) for methods evaluation equipment procurement, installation, and operation.	Magliano/Ranzieri
	F	Issue RFP(s) for data management equipment procurement and upgrades	Magliano/Ranzieri
	F	Issue RSOQ for quality assurance officer	Magliano/Ranzieri
Jul, 98	F	Define field monitoring RFPs. Coordinate writing of work statements with TC	McDade
	F	Evaluate responses to instrument comparison and data management RFPs and QA officer FSOQ and select investigators.	Magliano/TC
Aug, 98	F	Integrated data base complete from 1988-97	Niccum
	F	Draft field monitoring RFPs.	McDade/TC
	F	Initiate procurements and activities of QA, methods evaluation, and data management activities	Magliano/Ranzieri
Sep, 98	F		
Oct, 98	F	Revise field study plan, including RFPs and budget allocations	Watson/McDade
	F	Issue first round of field monitoring RFPs, established methods	Magliano/Ranzieri
Nov, 98	F	Initiate measurement evaluation study at Fresno	McDade/Meas invest.
		Initiate data base upgrades	
Jan, 99	F	Evaluate responses to first round field monitoring RFPs and select participants.	Magliano/TC
	F	Update data analysis plan, integrate field measurements with activities	Watson
	F	Update modeling plan, integrate field measurements with activities	Roth
Feb, 99	F	Functional and practical evaluation of measurement methods.	McDade/Meas. Invest.
Mar, 99	F	Draft QA plan	QA officer
	F	Issue second round of RFPs or sole-source procurements, specialized methods	Magliano/Ranzieri
Apr, 99	F	Finalize agreements with first round measurement investigators	Magliano/Ranzieri
	F	Draft QA plan	QA Officer
	F	Quantitative measurement evaluation study results	McDade/Meas. Invest.
May, 99	F	Evaluate responses to second round measurement RFP. Select investigators	Magliano/TCi
Jul, 99	F	Finalize agreements with second round measurement investigators	Magliano/Ranzieri

**Table 13.2-1**  
**CRPAQS Field Study Schedule, 1998-2001**

Date	Cate gory	Activity	Primary Responsibility
Aug, 99	F	Update field study plan, schedule and budget	McDade
	F	Update QA plan	QA officer
	F	Winter and annual measurement investigator workshop in Fresno	McDade
Oct, 99	F	Complete site selection, documentation, and upgrades	McDade
Nov, 99	F	Field deployment for Winter 99 field study	McDade/Meas. Investigators
Dec, 99	F	Begin winter 99 field study	McDade/Meas.
	F	Begin time-specific emissions studies	Magliano
	F	Begin annual field study	McDade/Meas. Investigators
	F	Field audits during first week, remedial action	QA Officer/ McDade
Jan, 00	F	Field audits during final part of winter study	
	F	End winter 99 field study	McDade/Meas. Investigators
Feb, 00	F	Issue third round field study RFPs or sole-source justifications, special measurements for autumn study	Magliano/Ranzieri
Apr, 00	F	Evaluate third round RFPs and select investigators	Magliano/TC
	F		
Jun, 00	F	Autumn field and emissions study workshop	McDade
Aug, 00	F	Autumn field study deployment	McDade/Measurement Invest.
	F	Integrated Data Base Complete from 1988-99	Niccum
mid-Sept, 00	F	Begin autumn field study monitoring	McDade/Meas. Investigators
Nov, 00	F	End Autumn Field Study	
Dec, 00	F	End Annual Field Study	
Jun, 00	F	Winter 99 Continuous Measurements in Data Base	
	F	Winter 99 PM <sub>2.5</sub> and PM <sub>10</sub> Mass Concentrations in Data Base	
Aug, 00	F	Integrated Data Base Complete from 1988-99	Niccum
Jan, 01	F	Winter 99 PM <sub>2.5</sub> and PM <sub>10</sub> Chemical Concentrations in Data Base	
Mar, 01		Winter 99 Data Documentation, Validation, and Documentation Complete	
		Integrated Data Base complete from 1998-February 2000	Niccum
Aug, 01		Integrated Data Base complete from 1998-2000	Niccum
		Need to add data analysis and modeling RFPs, proposal evaluation, workshops, draft reports, and final reports.	
		Also need to add in 1997/98 remaining technical support study reports.	

**Table 13.3-1.**  
**Estimated costs associated with individual program elements.**

<b>Program Element</b>	<b>Estimated Cost (\$k)</b>
Field study planning and management	1,050
Site selection, preparation, and leases	1,120
Winter 1998-99 measurement evaluation study	430
Annual measurement program	2,820
Winter measurement program	2,800
Fall measurement program	650
External QA	480
Data management	350
Emissions inventory	2,000
Data analysis and modeling	2,550
Study management	210
<b>TOTAL</b>	<b>14,460</b>

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